FreeBSD Developers' Handbook

摘要

歡迎使用 Developers' Handbook！ 這份文件是由許多人 不斷撰寫 而成的，
而且許多章節仍需更新或者內容還是一片空白， 如果你想幫忙 FreeBSD 文件計劃， 請寄信到 FreeBSD documentation project 郵遞論壇。

最新版的文件都在 FreeBSD 官網 上面， 也可從 FreeBSD FTP server 下載不同格式的資料。
當然也可以在其他的 mirror站下載。

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Part I: 基本概念

Chapter 1. 簡介

1.1. 在 FreeBSD 開發程式

好了我們開始吧！我想你的 FreeBSD 已經安裝好了，而且已經準備好要用它寫點程式了吧？
但是要從哪裡開始呢？ 有提供寫程式的程式或環境嗎？ 身為 programer 的我可以做什麼呢？

本章試著回答你一些問題，當然，單就 programming 程度來說可分很多種層次，
有的人只是單純當興趣，有的則是他的專業， 本章主要內容是針對程式初學者， 當然，對於那些不熟的程式開發者而言，本文件內容也是十分實用的。

1.2. The BSD Vision

為了讓你寫出來的程式在 like系統上具有良好的使用性、效能和穩定性，
我們必須跟你介紹一些程式概念(original software tools ideology)。

1.3. 程式架構指南

我們想介紹的概念如下

- 在整個程式還沒寫完前，不要增加新的功能。
- 另外一個重點就是，讓你自己選擇你的程式將會具有何種功能，
  而不是讓別人決定，不想要去滿足全世界的需求，除非你想讓你的程式具有擴充性或相容性。
- 千萬記住：在沒有相關經驗時，參考範例程式碼所寫出來的程式， 會比自己憑空寫出來的好。
- 當你寫的程式沒辦法完全解決問題時，最好的方法就是不要試著要去解決它。
- 若用 10% 的心力就能輕鬆完成 90% 的工作份量，就用這個簡單法子吧。
- 盡可能地簡化問題的複雜。
- 提供機制(mechanism)，而非原則(policy)。 比方說，把使用者介面選擇權交由使用者來決定。

以上摘自 Scheifler Gettys 的 "X Window System" 論文

1.4. /usr/src 的架構

完整的 FreeBSD 原始碼都在公開的 CVS repository 中。 通常 FreeBSD 原始碼都會裝在 /usr/src，
而且包含下列子目錄：

Directory	Description
bin/	Source for files in /bin
contrib/	Source for files from contributed software.
crypto/	Cryptographical sources
etc/	Source for files in /etc
games/	Source for files in /usr/games
gnu/	Utilities covered by the GNU Public License
include/	Source for files in /usr/include
kerberos5/	Source for Kerberos version 5
lib/	Source for files in /usr/lib
libexec/	Source for files in /usr/libexec
release/	Files required to produce a FreeBSD release
rescue/	Build system for the /rescue utilities

Directory	Description
sbin/	Source for files in /sbin
secure/	FreeSec sources
share/	Source for files in /usr/share
sys/	Kernel source files
tools/	Tools used for maintenance and testing of FreeBSD
usr.bin/	Source for files in /usr/bin
usr.sbin/	Source for files in /usr/sbin

Chapter 2. 程式開發工具

2.1. 概敘

本章將介紹如何使用一些 FreeBSD 所提供的程式開發工具(programing tools)，
本章所介紹的工具程式在其他版本的 上也可使用， 在此 並不會 嘗試描述寫程式時的每個細節，
本章大部分篇幅都是假設你以前沒有或只有少數的寫程式經驗，
不過，還是希望大多數的程式開發人員都能從中重新得到一些啟發。

2.2. 簡介

FreeBSD 提供一個非常棒的開發環境， 比如說像是 C、C++、Fortran 和
assembler(組合語言)的編譯器(compiler), 在 FreeBSD 中都已經包含在基本的系統中了 更別提 Perl
和其他標準 工具，像是sed 以及 awk， 如果你還是覺得不夠，FreeBSD在 Ports collection
中還提供其他的編譯器和直譯器(interpreter), FreeBSD 相容許多標準，像是 和 ANSI C，
當然還有它所繼承的 BSD 傳統。 所以在 FreeBSD
上寫的程式不需修改或頂多稍微修改，就可以在許多平台上編譯、執行。

無論如何，就算你從來沒在 平台上寫過程式，也可以徹底感受到FreeBSD 令人無法抗拒的迷人魔力。
本章的目標就是協助你快速上手，而暫時不需深入太多進階主題，
並且講解一些基礎概念，以讓你可以瞭解我們在講些什麼。

本章內容並不要求你得有程式開發經驗，或者你只有一點點的經驗而已。 不過，我們假設你已經會
系統的基本操作， 而且更重要的是，請保持樂於學習的心態！

2.3. Programming 概念

簡單的說，程式只是一堆指令的集合體；而這些指令是用來告訴電腦應該要作那些事情。
有時候，指令的執行取決於前一個指令的結果而定。 本章將會告訴你有 2
個主要的方法，讓你可以對電腦下達這些指示(instruction) 或 "命令(commands)"。 第一個方法就是
直譯器(interpreter)， 而第二個方法是 編譯器(compiler)。
由於對於電腦而言，人類語言的語意過於模糊而太難理解，
因此命令(commands)就常會以一種(或多種)程式語言寫成，用來指示電腦所要執行的特定動作為何。

2.3.1. 直譯器

使用直譯器時，所使用的程式語言就像變成一個會和你互動的環境。
當在命令提示列上打上命令時，直譯器會即時執行該命令。
在比較複雜的程式中，可以把所有想下達的命令統統輸入到某檔案裡面去，
然後呼叫直譯器去讀取該檔案，並且執行你寫在這個檔案中的指令。
如果所下的指令有錯誤產生，大多數的直譯器會進入偵錯模式(debugger)，
並且顯示相關錯誤訊息，以便對程式除錯。

這種方式好處在於：可以立刻看到指令的執行結果，以及錯誤也可迅速修正。
相對的，最大的壞處便是當你想把你寫的程式分享給其他人時，這些人必須要有跟你一樣的直譯器。
而且別忘了，他們也要會使用直譯器直譯程式才行。
當然使用者也不希望不小心按錯鍵，就進入偵錯模式而不知所措。
就執行效率而言，直譯器會使用到很多的記憶體，
而且這類直譯式程式，通常並不會比編譯器所編譯的程式的更有效率。

筆者個人認為，如果你之前沒有學過任何程式語言，最好先學學習直譯式語言(interpreted languages)，
像是 Lisp，Smalltalk，Perl 和 Basic 都是， 的 shell 像是 sh 和 csh
它們本身就是直譯器，事實上，很多人都在它們自己機器上撰寫各式的 shell "script"， 來順利完成各項
"housekeeping(維護)" 任務。 的使用哲學之一就是提供大量的小工具， 並使用 shell script
來組合運用這些小工具，以便工作更有效率。

2.3.2. FreeBSD 提供的直譯器

下面這邊有份 Ports Collection 所提供的直譯器清單，還有討論一些比較受歡迎的直譯式語言

至於如何使用 Ports Collection 安裝的說明，可參閱 FreeBSD Handbook 中的 Ports章節。

BASIC

BASIC 是 Beginner’s ALL-purpose Symbolic Instruction Code 的縮寫。 BASIC 於 1950 年代開始發展，最初開發這套語言的目的是為了教導當時的大學學生如何寫程式。 到了 1980，BASIC已經是很多 programmer 第一個學習的程式語言了。 此外，BASIC 也是 Visual Basic 的基礎。

FreeBSD Ports Collection 也有收錄相關的 BASIC 直譯器。 Bywater Basic 直譯器放在 lang/bwbasic。 而 Phil Cockroft’s Basic 直譯器(早期也叫 Rabbit Basic)放在 lang/pbasic。

Lisp

LISP 是在 1950 年代開始發展的一個直譯式語言，而且 LISP 就是一種 "number-crunching" languages(迅速進行大量運算的程式語言)，在當時算是一個普遍的程式語言。 LISP 的表達不是基於數字(numbers)，而是基於表(lists)。 而最能表示出 LISP 特色的地方就在於： LISP 是 "List Processing" 的縮寫。 在人工智慧(Artificial Intelligence, AI)領域上 LISP 的各式應用非常普遍。

LISP 是非常強悍且複雜的程式語言，但是缺點是程式碼會非常大而且難以操作。

絕大部分的 LISP 直譯器都可以在 系統上運作，當然 的 Ports Collection 也有收錄。 GNU Common Lisp 收錄在 lang/gcl， Bruno Haible 和 Michael Stoll 的 CLISP 收錄在 lang/clisp ，此外 CMUCL(包含一個已經最佳化的編譯器)， 以及其他簡化版的 LISP 直譯器(比如以 C 語言寫的 SLisp，只用幾百行程式碼就實作大多數 Common Lisp 的功能) 則是分別收錄在 lang/cmucl 以及 lang/slisp。

Perl

對系統管理者而言，最愛用 perl 來撰寫 scripts 以管理主機， 同時也經常用來寫 WWW 主機上的 CGI Script 程式。

Perl 在 Ports Collection 內的 lang/perl5。 而 4.X 則是把 Perl 裝在 /usr/bin/perl。

Scheme

Scheme 是 LISP 的另一分支，Scheme 的特點就是比 Common LISP 還要簡潔有力。 由於 Scheme 簡單，所以很多大學拿來當作第一堂程式語言教學教材。
而且對於研究人員來說也可以快速的開發他們所需要的程式。

Scheme 收錄在 lang/elk， Elk Scheme 直譯器(由麻省理工學院所發展的 Scheme 直譯器)收錄在 lang/mit-scheme， SCM Scheme Interpreter 收錄在 lang/scm。

Icon

Icon 屬高階程式語言，Icon 具有強大的字串(String)和結構(Structure)處理能力。 Ports Collection 所收錄的 Icon 直譯器版本則是放在 lang/icon。

Logo

Logo 是種容易學習的程式語言，最常在一些教學課程中被拿來當作開頭範例。
如果要給小朋友開始上程式語言課的話，Logo 是相當不錯的選擇。 因為，即使對小朋友來說，要用 Logo 來秀出複雜多邊形圖形是相當輕鬆容易的。

Logo 在 Ports Collection 的最新版則是放在 lang/logo。

Python

Python 是物件導向的直譯式語言， Python 的擁護者總是宣稱 Python 是最好入門的程式語言。 雖然 Python 可以很簡單的開始，但是不代表它就會輸給其他直譯式語言(像是 Perl 和 Tcl)， 事實證明 Python 也可以拿來開發大型、複雜的應用程式。

Ports Collection 收錄在 lang/python。

Ruby

Ruby 是純物件導向的直譯式語言。 Ruby
目前非常流行，原因在於他易懂的程式語法結構，在撰寫程式時的彈性，
以及天生具有輕易的發展維護大型專案的能力。

Ports Collection 收錄在 lang/ruby8。

Tcl and Tk

Tcl 是內嵌式的直譯式語言，讓 Tcl 可以如此廣泛運用的原因是 Tcl 的移植性。 Tcl
也可以快速發展一個簡單但是具有雛型的程式或者具有完整功能的程式。

Tcl 許多的版本都可在 上運作，而最新的 Tcl 版本為 Tcl 8.4， Ports Collection 收錄在 lang/tcl84。

2.3.3. 編譯器

編譯器和直譯器兩者相比的話，有些不同，首先就是必須先把程式碼統統寫入到檔案裡面，
然後必須執行編譯器來試著編譯程式，如果編譯器不接受所寫的程式，那就必須一直修改程式，
直到編譯器接受且把你的程式編譯成執行檔。
此外，也可以在提示命令列，或在除錯器中執行你編譯好的程式看看它是否可以運作。

很明顯的，使用編譯器並不像直譯器般可以馬上得到結果。
不管如何，編譯器允許你作很多直譯器不可能或者是很難達到的事情。
例如：撰寫和作業系統密切互動的程式，甚至是你自己寫的作業系統！
當你想要寫出高效率的程式時，編譯器便派上用場了。
編譯器可以在編譯時順便最佳化你的程式，但是直譯器卻不行。
而編譯器與直譯器最大的差別在於：當你想把你寫好的程式拿到另外一台機器上跑時，
你只要將編譯器編譯出來的可執行檔，拿到新機器上便可以執行，
而直譯器則必須要求新機器上，必須要有跟另一台機器上相同的直譯器， 才能組譯執行你的程式！

編譯式的程式語言包含 Pascal、C 和 c++， C 和 c++ 不是一個親和力十足的語言，但是很適合具有經驗的 Programmer。 Pascal 其實是一個設計用來教學用的程式語言，而且也很適合用來入門， 預設並沒有把 Pascal 整合進 base system 中， 但是 GNU Pascal Compiler 和 Free Pascal Compiler 都可分別在 lang/gpc 和 lang/fpc 中找到。

如果你用不同的程式來寫編譯式程式，那麼不斷地編輯-編譯-執行-除錯的這個循環肯定會很煩人，
為了更簡化、方便程式開發流程，很多商業編譯器廠商開始發展所謂的 IDE (Integrated Development Environments) 開發環境， FreeBSD 預設並沒有把 IDE 整合進 base system 中， 但是你可透過 devel/kdevelop 安裝 kdevelop 或使用 Emacs 來體驗 IDE 開發環境。 在後面的 Using Emacs as a Development Environment 專題將介紹，如何以 Emacs 來作為 IDE 開發環境。

2.4. 用 cc 來編譯程式

本章範例只有針對 GNU C compiler 和 GNU C++ compiler 作說明， 這兩個在 FreeBSD base system 中就有了， 直接打 cc 或 gcc 就可以執行。
至於，如何用直譯器產生程式的說明，通常可在直譯器的文件或線上文件找到說明，因此不再贅述。

當你寫完你的傑作後，接下來便是讓這個程式可以在 FreeBSD 上執行，
通常這些要一些步驟才能完成，有些步驟則需要不同程式來完成。

1. 預先處理(Pre-process)你的程式碼，移除程式內的註解，和其他技巧， 像是 expanding(擴大) C 的 marco。
2. 確認你的程式語法是否確實遵照 C/C++ 的規定，如果沒有符合的話，編譯器會出現警告。
3. 將原始碼轉成組合語言 它跟機器語言(machine code)非常相近，但仍在人類可理解的範圍內(據說應該是這樣)。
4. 把組合語言轉成機器語言 是的，這裡說的機器語言就是常提到的 bit 和 byte，也就是 1 和 0。
5. 確認程式中用到的函式呼叫、全域變數是否正確，舉例來說：如若呼叫了不存在的函式，編譯器會顯示警告。

6. 如果程式是由程式碼檔案來編譯，編譯器會整合起來。
7. 編譯器會負責產生東西，讓系統上的 run-time loader 可以把程式載入記憶體內執行。
8. 最後會把編譯完的執行檔存在硬碟上。

通常 編譯(compiling) 是指第 1 到第 4 個步驟。 其他步驟則稱為 連結(linking)， 有時候步驟 1 也可以是指預先處理(pre-processing)， 而步驟 3 到步驟 4 則是 組譯(assembling)。

幸運的是，你可以不用理會以上細節，編譯器都會自動完成。 因為 cc 只是是個前端程式(front end)，它會依照正確的參數來呼叫相關程式幫你處理。 只需打：

```
% cc foobar.c
```

上述指令會把 foobar.c 開始編譯，並完成上述動作。
如果你有許多檔案需要編譯，那請打類似下列指令即可：

```
% cc foo.c bar.c
```

記住語法錯誤檢查就是 純粹檢查語法錯誤與否，
而不會幫你檢測任何邏輯錯誤，比如：無限迴圈，或是排序方式想用 binary sort 卻弄成 bubble sort。

cc 有非常多的選項，都可透過線上手冊來查。 下面只提一些必要且重要的選項，以作為例子。

-o 檔名

-o 編譯後的執行檔檔名，如果沒有使用這選項的話， 編譯好的程式預設檔名將會是 a.out

```
% cc foobar.c           執行檔就是 a.out
% cc -o foobar foobar.c    執行檔就是 foobar
```

-c

使用 -c 時，只會編譯原始碼，而不作連結(linking)。 當只想確認語法是否正確或使用 Makefile 來編譯程式時，這個選項非常有用。

```
% cc -c foobar.c
```

這會產生叫做 foobar 的 object file(非執行檔)。 這檔可以與其他的 object file 連結在一起，而成執行檔。

-g

-g 將會把一些給 gdb 用的除錯訊息包進去執行檔裡面，所謂的除錯訊息例如：
程式在第幾行出錯、那個程式第幾行做什麼函式呼叫等等。除錯資訊非常好用。
但缺點就是：對於程式來說，額外的除錯訊息會讓編譯出來的程式比較肥些。 -g 的適用時機在於：當程式還在開發時使用就好， 而當你要釋出你的 "發行版本(release version)" 或者確認程式可運作正常的話，就不必用 -g 這選項了。

```
% cc -g foobar.c
```

這動作會產生有含除錯訊息的執行檔。

-O

-O 會產生最佳化的執行檔， 編譯器會使用一些技巧，來讓程式可以跑的比未經最佳化的程式還快，
可以在大寫 O 後面加上數字來指明想要的最佳化層級。 但是最佳化還是會有一些錯誤，舉例來說在
FreeBSD 2.10 release 中用 cc 且指定 -O2 時，在某些情形下會產生錯誤的執行檔。

只有當要釋出發行版本、或者加速程式時，才需要使用最佳化選項。

```
% cc -O -o foobar foobar.c
```

這會產生 foobar 執行檔的最佳化版本。

以下三個參數將會強迫 cc 確認程式碼是否符合一些國際標準的規範， 也就是通常說的 ANSI 標準， 而 ANSI
嚴格來講屬 ISO 標準。

-Wall

-Wall 顯示 cc 維護者所認為值得注意的所有警告訊息。
不過這名字可能會造成誤解，事實上它並未完全顯示 cc 所能注意到的各項警告訊息。

-ansi

-ansi 關閉 cc 特有的某些特殊非 ANSI C 標準功能。
不過這名字可能會造成誤解，事實上它並不保證你的程式會完全符合 ANSI 標準。

-pedantic

全面關閉 cc 所特有的非 ANSI C 標準功能。

除了這些參數，cc 還允許你使用一些額外的參數取代標準參數，有些額外參數非常有用，
但是實際上並不是所有的編譯器都有提供這些參數。
照標準來寫程式的最主要目的就是，希望你寫出來的程式可以在所有編譯器上編譯、執行無誤，
當程式可以達成上述目的時，就稱為 portable code(移植性良好的程式碼)。

一般來說，在撰寫程式時就應要注意『移植性』。
否則。當想把程式拿到另外一台機器上跑的時候，就可能得需要重寫程式。

```
% cc -Wall -ansi -pedantic -o foobar foobar.c
```

上述指令會確認 foobar.c 內的語法是否符合標準， 並且產生名為 foobar 的執行檔。

-l library

告訴 gcc 在連結(linking)程式時你需要用到的函式庫名稱。

最常見的情況就是，當你在程式中使用了 C 數學函式庫，
跟其他作業平台不一樣的是，這函示學函式都不在標準函式庫(library)中，
因此編譯器並不知道這函式庫名稱，你必須告訴編譯器要加上它才行。

規則很簡單，如果有個函式庫叫做 libsomething.a， 就必須在編譯時加上參數 -l something 才行。
舉例來說，數學函式庫叫做 libm.a， 所以你必須給 cc 的參數就是 -lm。
一般情況下，通常會把這參數必須放在指令的最後。

```
% cc -o foobar foobar.c -lm
```

上面這指令會讓 gcc 跟數學函式庫作連結，以便你的程式可以呼叫函式庫內含的數學函式。

如果你正在編譯的程式是 C++ 程式碼，你還必須額外指定 -lg++ 或者是 -lstdc++。 如果你的 FreeBSD 是
2.2(含)以後版本， 你可以用指令 c++ 來取代 cc。 在 FreeBSD 上 c++ 也可以用 g++ 取代。

```
% cc -o foobar foobar.cc -lg++    適用 FreeBSD 2.1.6 或更早期的版本
% cc -o foobar foobar.cc -lstdc++ 適用 FreeBSD 2.2 及之後的版本
% c++ -o foobar foobar.cc
```

上述指令都會從原始檔 foobar.cc 編譯產生名為 fooboar 的執行檔。 這邊要提醒的是在 系統中 c++ 程式傳統都以 .C、 .cxx 或者是 .cc 作為副檔名， 而非 那種以 .cpp 作為副檔名的命名方式(不過也越來越普遍了)。 gcc 會依副檔名來決定用哪一種編譯器編譯， 然而，現在已經不再限制副檔名了， 所以可以自由的使用 .cpp 作為 c++ 程式碼的副檔名！

2.4.1. 常見的 cc 問題

2.4.1.1. 我用 sin() 函示撰寫我的程式， 但是有個錯誤訊息(如下)，這代表著？

```
/var/tmp/cc0143941.o: Undefined symbol `_sin' referenced from text segment
```

當使用 sin() 這類的數學函示時， 你必須告訴 cc 要和數學函式庫作連結(linking)，就像這樣：

```
% cc temp.c -lm
```

2.4.1.2. 好吧，我試著寫些簡單的程式，來練習使用 -lm 選項(該程式會運算 2.1 的 6 次方)

當編譯器發現你呼叫一個函示時，它會確認該函示的回傳值類型(prototype)， 如果沒有特別指明，則預設的回傳值類型為 int(整數)。 很明顯的，你的程式所需要的並不是回傳值類別為 int。

2.4.1.3. 那如何才可以修正剛所說的問題？

數學函示的回傳值類型(prototype)會定義在 math.h， 如果你有 include 這檔，編譯器就會知道該函示的回傳值類型，如此一來該運算就會得到正確的結果！

```
#include <stdio.h>

int main() {
   float f;

   f = pow(2.1, 6);
   printf("2.1 ^ 6 = %f\n", f);
   return 0;
}
```

編譯後執行程式，得到下面這結果：

```
% cc temp.c -lm
```

加了上述內容之後，再重新編譯，最後執行：

```
% ./a.out
2.1 ^ 6 = 85.766121
```

如果有用到數學函式，請確定要有 include math.h 這檔， 而且記得要和數學函式庫作連結。

2.4.1.4. 已經編譯好 foobar.c， 但是編譯後找不到 foobar 執行檔。 該去哪邊找呢？

記得，除非有指定編譯結果的執行檔檔名，否則預設的執行檔檔名是 a.out。 用 -o filename 參數，
就可以達到所想要的結果，比如：

```
% cc -o foobar foobar.c
```

2.4.1.5. 好，有個編譯好的程式叫做 foobar， 用 ls 指令時可以看到，
但執行時，訊息卻說卻沒有這檔案。為什麼？

與 不同的是，除非有指定執行檔的路徑， 否則 系統並不會在目前的目錄下尋找你想執行的檔案。
在指令列下打 ./foobar 代表 "執行在這個目錄底下名為 foobar 的程式"， 或者也可以更改 PATH
環境變數設定如下，以達成類似效果：

```
bin:/usr/bin:/usr/local/bin:.
```

上一行最後的 "." 代表"如果在前面寫的其他目錄找不到，就找目前的目錄"。

2.4.1.6. 試著執行 test 執行檔， 但是卻沒有任何事發生，到底是哪裡出錯了？

大多數的 系統都會在路徑 /usr/bin 擺放執行檔。 除非有指定使用在目前目錄內的 test，否則 shell
會優先選擇位在 /usr/bin 的 test， 要指定檔名的話，作法類似：

```
% ./test
```

為了避免上述困擾，請為你的程式取更好的名稱吧！

2.4.1.7. 當執行我寫的程式時剛開始正常， 接下來卻出現 core dumped
錯誤訊息。這錯誤訊息到底代表什麼？

關於 core dumped 這個名稱的由來， 可以追溯到早期的 系統開始使用 core memory 對資料排序時。
基本上當程式在很多情況下發生錯誤後， 作業系統會把 core memory 中的資訊寫入 core 這檔案中，
以便讓 programmer 知道程式到底是為何出錯。

2.4.1.8. 真是太神奇了！程式居然發生 core dumped 了，該怎麼辦？

請用 gdb 來分析 core 結果(詳情請參考 Debugging)。

2.4.1.9. 當程式已經把 core memory 資料 dump 出來後， 同時也出現另一個錯誤 segmentation fault
這意思是？

基本上，這個錯誤表示你的程式在記憶體中試著做一個嚴重的非法運作(illegal operation)，
就是被設計來保護整個作業系統免於被惡質的程式破壞，所以才會告訴你這個訊息。

最常造成"segmentation fault"的原因通常為：

- 試著對一個 NULL 的指標(pointer)作寫入的動作，如

```
char *foo = NULL;
strcpy(foo, "bang!");
```

- 使用一個尚未初始化(initialized)的指標，如：

```
char *foo;
strcpy(foo, "bang!");
```

尚未初始化的指標的初始值將會是隨機的，如果你夠幸運的話， 這個指標的初始值會指向 kernel 已經用到的記憶體位置， kernel 會結束掉這個程式以確保系統運作正常。如果你不夠幸運，初始指到的記憶體位置是你程式必須要用到的資料結構(data structures)的位置，當這個情形發生時程式將會當的不知其所以然。

- 試著寫入超過陣列(array)元素個數，如：

```
int bar[20];
bar[27] = 6;
```

- 試著讀寫在唯讀記憶體(read-only memory)中的資料，如：

```
char *foo = "My string";
strcpy(foo, "bang!");
```

UNIX® compilers often put string literals like "My string" into read-only areas of memory.

- Doing naughty things with malloc() and free(), eg

```
char bar[80];
free(bar);
```

or

```
char *foo = malloc(27);
free(foo);
free(foo);
```

Making one of these mistakes will not always lead to an error, but they are always bad practice. Some systems and compilers are more tolerant than others, which is why programs that ran well on one system can crash when you try them on an another.

2.4.1.10. Sometimes when I get a core dump it says bus error. It says in my UNIX® book that this means a hardware problem, but the computer still seems to be working. Is this true?

No, fortunately not (unless of course you really do have a hardware problem…). This is usually another way of saying that you accessed memory in a way you should not have.

2.4.1.11. This dumping core business sounds as though it could be quite useful, if I can make it happen when I want to. Can I do this, or do I have to wait until there is an error?

Yes, just go to another console or xterm, do

```
% ps
```

to find out the process ID of your program, and do

```
% kill -ABRT pid
```

where pid is the process ID you looked up.

This is useful if your program has got stuck in an infinite loop, for instance. If your program happens to trap SIGABRT, there are several other signals which have a similar effect.

Alternatively, you can create a core dump from inside your program, by calling the abort() function. See the manual page of abort(3) to learn more.

If you want to create a core dump from outside your program, but do not want the process to terminate, you can use the gcore program. See the manual page of gcore(1) for more information.

2.5. Make

2.5.1. What is make?

When you are working on a simple program with only one or two source files, typing in

```
% cc file1.c file2.c
```

is not too bad, but it quickly becomes very tedious when there are several files-and it can take a while to compile, too.

One way to get around this is to use object files and only recompile the source file if the source code has changed. So we could have something like:

```
% cc file1.o file2.o ⋯ file37.c ⋯
```

if we had changed file37.c, but not any of the others, since the last time we compiled. This may speed up the compilation quite a bit, but does not solve the typing problem.

Or we could write a shell script to solve the typing problem, but it would have to re-compile everything, making it very inefficient on a large project.

What happens if we have hundreds of source files lying about? What if we are working in a team with other people who forget to tell us when they have changed one of their source files that we use?

Perhaps we could put the two solutions together and write something like a shell script that would contain some kind of magic rule saying when a source file needs compiling. Now all we need now is a program that can understand these rules, as it is a bit too complicated for the shell.

This program is called make. It reads in a file, called a makefile, that tells it how different files depend on each other, and works out which files need to be re-compiled and which ones do not.

For example, a rule could say something like "if fromboz.o is older than fromboz.c, that means someone must have changed fromboz.c, so it needs to be re-compiled." The makefile also has rules telling make how to re-compile the source file, making it a much more powerful tool.

Makefiles are typically kept in the same directory as the source they apply to, and can be called makefile, Makefile or MAKEFILE. Most programmers use the name Makefile, as this puts it near the top of a directory listing, where it can easily be seen.[1]

2.5.2. Example of Using make

Here is a very simple make file:

```
foo: foo.c
  cc -o foo foo.c
```

It consists of two lines, a dependency line and a creation line.

The dependency line here consists of the name of the program (known as the target), followed by a colon, then whitespace, then the name of the source file. When make reads this line, it looks to see if foo exists; if it exists, it compares the time foo was last modified to the time foo.c was last modified. If foo does not exist, or is older than foo.c, it then looks at the creation line to find out what to do. In other words, this is the rule for working out when foo.c needs to be re-compiled.

The creation line starts with a tab (press `tab`) and then the command you would type to create foo if you were doing it at a command prompt. If foo is out of date, or does not exist, make then executes this command to create it. In other words, this is the rule which tells make how to re-compile foo.c.

So, when you type make, it will make sure that foo is up to date with respect to your latest changes to foo.c. This principle can be extended to Makefile's with hundreds of targets-in fact, on FreeBSD, it is possible to compile the entire operating system just by typing make world in the appropriate directory!

Another useful property of makefiles is that the targets do not have to be programs. For instance, we could have a make file that looks like this:

```
foo: foo.c
  cc -o foo foo.c

install:
  cp foo /home/me
```

We can tell make which target we want to make by typing:

```
% make target
```

make will then only look at that target and ignore any others. For example, if we type make foo with the makefile above, make will ignore the install target.

If we just type make on its own, make will always look at the first target and then stop without looking at any others. So if we typed make here, it will just go to the foo target, re-compile foo if necessary, and then stop without going on to the install target.

Notice that the install target does not actually depend on anything! This means that the command on the following line is always executed when we try to make that target by typing make install. In

this case, it will copy foo into the user's home directory. This is often used by application makefiles, so that the application can be installed in the correct directory when it has been correctly compiled.

This is a slightly confusing subject to try to explain. If you do not quite understand how make works, the best thing to do is to write a simple program like "hello world" and a make file like the one above and experiment. Then progress to using more than one source file, or having the source file include a header file. touch is very useful here-it changes the date on a file without you having to edit it.

2.5.3. Make and include-files

C code often starts with a list of files to include, for example stdio.h. Some of these files are system-include files, some of them are from the project you are now working on:

```
#include <stdio.h>
#include "foo.h"

int main(....
```

To make sure that this file is recompiled the moment foo.h is changed, you have to add it in your Makefile:

```
foo: foo.c foo.h
```

The moment your project is getting bigger and you have more and more own include-files to maintain, it will be a pain to keep track of all include files and the files which are depending on it. If you change an include-file but forget to recompile all the files which are depending on it, the results will be devastating. clang has an option to analyze your files and to produce a list of include-files and their dependencies: -MM.

If you add this to your Makefile:

```
depend:
  cc -E -MM *.c > .depend
```

and run make depend, the file .depend will appear with a list of object-files, C-files and the include-files:

```
foo.o: foo.c foo.h
```

If you change foo.h, next time you run make all files depending on foo.h will be recompiled.

Do not forget to run make depend each time you add an include-file to one of your files.

2.5.4. FreeBSD Makefiles

Makefiles can be rather complicated to write. Fortunately, BSD-based systems like FreeBSD come with some very powerful ones as part of the system. One very good example of this is the FreeBSD ports system. Here is the essential part of a typical ports Makefile:

```
MASTER_SITES=  ftp://freefall.cdrom.com/pub/FreeBSD/LOCAL_PORTS/
DISTFILES=     scheme-microcode+dist-7.3-freebsd.tgz

.include <bsd.port.mk>
```

Now, if we go to the directory for this port and type make, the following happens:

1. A check is made to see if the source code for this port is already on the system.
2. If it is not, an FTP connection to the URL in MASTER_SITES is set up to download the source.
3. The checksum for the source is calculated and compared it with one for a known, good, copy of the source. This is to make sure that the source was not corrupted while in transit.
4. Any changes required to make the source work on FreeBSD are applied-this is known as patching.
5. Any special configuration needed for the source is done. (Many UNIX® program distributions try to work out which version of UNIX® they are being compiled on and which optional UNIX® features are present-this is where they are given the information in the FreeBSD ports scenario).
6. The source code for the program is compiled. In effect, we change to the directory where the source was unpacked and do make-the program's own make file has the necessary information to build the program.
7. We now have a compiled version of the program. If we wish, we can test it now; when we feel confident about the program, we can type make install. This will cause the program and any supporting files it needs to be copied into the correct location; an entry is also made into a package database, so that the port can easily be uninstalled later if we change our mind about it.

Now I think you will agree that is rather impressive for a four line script!

The secret lies in the last line, which tells make to look in the system makefile called bsd.port.mk. It is easy to overlook this line, but this is where all the clever stuff comes from-someone has written a makefile that tells make to do all the things above (plus a couple of other things I did not mention, including handling any errors that may occur) and anyone can get access to that just by putting a single line in their own make file!

If you want to have a look at these system makefiles, they are in /usr/shared/mk, but it is probably best to wait until you have had a bit of practice with makefiles, as they are very complicated (and if you do look at them, make sure you have a flask of strong coffee handy!)

2.5.5. More Advanced Uses of make

Make is a very powerful tool, and can do much more than the simple example above shows. Unfortunately, there are several different versions of make, and they all differ considerably. The best way to learn what they can do is probably to read the documentation-hopefully this introduction will have given you a base from which you can do this.

The version of make that comes with FreeBSD is the Berkeley make; there is a tutorial for it in /usr/shared/doc/psd/12.make. To view it, do

```
% zmore paper.ascii.gz
```

in that directory.

Many applications in the ports use GNU make, which has a very good set of "info" pages. If you have installed any of these ports, GNU make will automatically have been installed as gmake. It is also available as a port and package in its own right.

To view the info pages for GNU make, you will have to edit dir in the /usr/local/info directory to add an entry for it. This involves adding a line like

```
* Make: (make).          The GNU Make utility.
```

to the file. Once you have done this, you can type info and then select make from the menu (or in Emacs, do C-h i).

2.6. Debugging

2.6.1. Introduction to Available Debuggers

Using a debugger allows running the program under more controlled circumstances. Typically, it is possible to step through the program a line at a time, inspect the value of variables, change them, tell the debugger to run up to a certain point and then stop, and so on. It is also possible to attach to a program that is already running, or load a core file to investigate why the program crashed. It is even possible to debug the kernel, though that is a little trickier than the user applications we will be discussing in this section.

This section is intended to be a quick introduction to using debuggers and does not cover specialized topics such as debugging the kernel. For more information about that, refer to Kernel Debugging.

The standard debugger supplied with FreeBSD 12.1 is called lldb (LLVM debugger). As it is part of the standard installation for that release, there is no need to do anything special to use it. It has good command help, accessible via the help command, as well as a web tutorial and documentation.

The lldb command is available for FreeBSD 11.3 from ports or packages as devel/llvm. This will install the default version of lldb (currently 9.0).

The other debugger available with FreeBSD is called gdb (GNU debugger). Unlike lldb, it is not installed by default on FreeBSD 12.1; to use it, install devel/gdb from ports or packages. The version installed by default on FreeBSD 11.3 is old; instead, install devel/gdb there as well. It has quite good on-line help, as well as a set of info pages.

Which one to use is largely a matter of taste. If familiar with one only, use that one. People familiar with neither or both but wanting to use one from inside Emacs will need to use gdb as lldb is unsupported by Emacs. Otherwise, try both and see which one you prefer.

2.6.2. Using lldb

2.6.2.1. Starting lldb

Start up lldb by typing

```
% lldb -- progname
```

2.6.2.2. Running a Program with lldb

Compile the program with -g to get the most out of using lldb. It will work without, but will only display the name of the function currently running, instead of the source code. If it displays a line

like:

```
Breakpoint 1: where = temp`main, address = ⋯
```

(without an indication of source code filename and line number) when setting a breakpoint, this means that the program was not compiled with -g.

Most lldb commands have shorter forms that can be used instead. The longer forms are used here for clarity.

At the lldb prompt, type breakpoint set -n main. This will tell the debugger not to display the preliminary set-up code in the program being run and to stop execution at the beginning of the program's code. Now type process launch to actually start the program- it will start at the beginning of the set-up code and then get stopped by the debugger when it calls main().

To step through the program a line at a time, type thread step-over. When the program gets to a function call, step into it by typing thread step-in. Once in a function call, return from it by typing thread step-out or use up and down to take a quick look at the caller.

Here is a simple example of how to spot a mistake in a program with lldb. This is our program (with a deliberate mistake):

```
#include <stdio.h>

int bazz(int anint);

main() {
   int i;

   printf("This is my program\n");
   bazz(i);
   return 0;
}

int bazz(int anint) {
   printf("You gave me %d\n", anint);
   return anint;
}
```

This program sets i to be 5 and passes it to a function bazz() which prints out the number we gave it.

Compiling and running the program displays

```
% cc -g -o temp temp.c
% ./temp
This is my program
anint = -5360
```

That is not what was expected! Time to see what is going on!

```
% lldb -- temp
(lldb) target create "temp"
Current executable set to 'temp' (x86_64).
(lldb) breakpoint set -n main            Skip the set-up code
Breakpoint 1: where = temp`main + 15 at temp.c:8:2, address = 0x00000000002012ef    lldb
puts breakpoint at main()
(lldb) process launch                Run as far as main()
Process 9992 launching
Process 9992 launched: '/home/pauamma/tmp/temp' (x86_64)    Program starts running

Process 9992 stopped
* thread #1, name = 'temp', stop reason = breakpoint 1.1    lldb stops at main()
    frame #0: 0x00000000002012ef temp`main at temp.c:8:2
   5    main() {
   6        int i;
   7
-> 8        printf("This is my program\n");       Indicates the line where it stopped
   9        bazz(i);
   10       return 0;
   11   }
(lldb) thread step-over       Go to next line
This is my program                Program prints out
Process 9992 stopped
* thread #1, name = 'temp', stop reason = step over
    frame #0: 0x0000000000201300 temp`main at temp.c:9:7
   6        int i;
   7
   8        printf("This is my program\n");
-> 9        bazz(i);
   10       return 0;
   11   }
   12
(lldb) thread step-in         step into bazz()
Process 9992 stopped
* thread #1, name = 'temp', stop reason = step in
    frame #0: 0x000000000020132b temp`bazz(anint=-5360) at temp.c:14:29 lldb displays
stack frame
   11   }
   12
   13   int bazz(int anint) {
-> 14       printf("You gave me %d\n", anint);
```

```
  15     return anint;
  16  }
(lldb)
```

Hang on a minute! How did anint get to be -5360? Was it not set to 5 in main()? Let us move up to main() and have a look.

```
(lldb) up     Move up call stack
frame #1: 0x000000000020130b temp`main at temp.c:9:2     lldb displays stack frame
   6     int i;
   7
   8     printf("This is my program\n");
-> 9      bazz(i);
   10    return 0;
   11 }
   12
(lldb) frame variable i      Show us the value of i
(int) i = -5360              lldb displays -5360
```

Oh dear! Looking at the code, we forgot to initialize i. We meant to put

```
...
main() {
   int i;

   i = 5;
   printf("This is my program\n");
...
```

but we left the i=5; line out. As we did not initialize i, it had whatever number happened to be in that area of memory when the program ran, which in this case happened to be -5360.

The lldb command displays the stack frame every time we go into or out of a function, even if we are using up and down to move around the call stack. This shows the name of the function and the values of its arguments, which helps us keep track of where we are and what is going on. (The stack is a storage area where the program stores information about the arguments passed to functions and where to go when it returns from a function call.)

2.6.2.3. Examining a Core File with lldb

A core file is basically a file which contains the complete state of the process when it crashed. In "the good old days", programmers had to print out hex listings of core files and sweat over machine code manuals, but now life is a bit easier. Incidentally, under FreeBSD and other 4.4BSD systems, a core file is called progname.core instead of just core, to make it clearer which program a core file belongs to.

To examine a core file, specify the name of the core file in addition to the program itself. Instead of starting up lldb in the usual way, type lldb -c progname.core -- progname.

The debugger will display something like this:

```
% lldb -c progname.core -- progname
(lldb) target create "progname" --core "progname.core"
Core file '/home/pauamma/tmp/progname.core' (x86_64) was loaded.
(lldb)
```

In this case, the program was called progname, so the core file is called progname.core. The debugger does not display why the program crashed or where. For this, use thread backtrace all. This will also show how the function where the program dumped core was called.

```
(lldb) thread backtrace all
* thread #1, name = 'progname', stop reason = signal SIGSEGV
  * frame #0: 0x0000000000201347 progname`bazz(anint=5) at temp2.c:17:10
    frame #1: 0x0000000000201312 progname`main at temp2.c:10:2
    frame #2: 0x000000000020110f progname`_start(ap=<unavailable>,
cleanup=<unavailable>) at crt1.c:76:7
(lldb)
```

SIGSEGV indicates that the program tried to access memory (run code or read/write data usually) at a location that does not belong to it, but does not give any specifics. For that, look at the source code at line 10 of file temp2.c, in bazz(). The backtrace also says that in this case, bazz() was called from main().

2.6.2.4. Attaching to a Running Program with lldb

One of the neatest features about lldb is that it can attach to a program that is already running. Of course, that requires sufficient permissions to do so. A common problem is stepping through a program that forks and wanting to trace the child, but the debugger will only trace the parent.

To do that, start up another lldb, use ps to find the process ID for the child, and do

```
(lldb) process attach -p pid
```

in lldb, and then debug as usual.

For that to work well, the code that calls fork to create the child needs to do something like the following (courtesy of the gdb info pages):

```
...
if ((pid = fork()) < 0)     /* _Always_ check this */
  error();
else if (pid == 0) {      /* child */
  int PauseMode = 1;

  while (PauseMode)
    sleep(10);  /* Wait until someone attaches to us */
  ...
```

```
} else {        /* parent */
  ...
```

Now all that is needed is to attach to the child, set PauseMode to 0 with expr PauseMode = 0 and wait for the sleep() call to return.

2.6.3. Using gdb

2.6.3.1. Starting gdb

Start up gdb by typing

```
% gdb progname
```

although many people prefer to run it inside Emacs. To do this, type:

```
M-x gdb RET progname RET
```

Finally, for those finding its text-based command-prompt style off-putting, there is a graphical front-end for it (devel/xxgdb) in the Ports Collection.

2.6.3.2. Running a Program with gdb

Compile the program with -g to get the most out of using gdb. It will work without, but will only display the name of the function currently running, instead of the source code. A line like:

```
... (no debugging symbols found) ...
```

when gdb starts up means that the program was not compiled with -g.

At the gdb prompt, type break main. This will tell the debugger to skip the preliminary set-up code in the program being run and to stop execution at the beginning of the program's code. Now type run to start the program- it will start at the beginning of the set-up code and then get stopped by the debugger when it calls main().

To step through the program a line at a time, press n. When at a function call, step into it by pressing s. Once in a function call, return from it by pressing f, or use up and down to take a quick look at the caller.

Here is a simple example of how to spot a mistake in a program with gdb. This is our program (with a deliberate mistake):

```
#include <stdio.h>

int bazz(int anint);

main() {
  int i;

  printf("This is my program\n");
```

```
    bazz(i);
    return 0;
}

int bazz(int anint) {
    printf("You gave me %d\n", anint);
    return anint;
}
```

This program sets i to be 5 and passes it to a function bazz() which prints out the number we gave it.

Compiling and running the program displays

```
% cc -g -o temp temp.c
% ./temp
This is my program
anint = 4231
```

That was not what we expected! Time to see what is going on!

```
% gdb temp
GDB is free software and you are welcome to distribute copies of it
 under certain conditions; type "show copying" to see the conditions.
There is absolutely no warranty for GDB; type "show warranty" for details.
GDB 4.13 (i386-unknown-freebsd), Copyright 1994 Free Software Foundation, Inc.
(gdb) break main            Skip the set-up code
Breakpoint 1 at 0x160f: file temp.c, line 9.   gdb puts breakpoint at main()
(gdb) run              Run as far as main()
Starting program: /home/james/tmp/temp     Program starts running

Breakpoint 1, main () at temp.c:9      gdb stops at main()
(gdb) n              Go to next line
This is my program          Program prints out
(gdb) s              step into bazz()
bazz (anint=4231) at temp.c:17        gdb displays stack frame
(gdb)
```

Hang on a minute! How did anint get to be 4231? Was it not set to 5 in main()? Let us move up to main() and have a look.

```
(gdb) up              Move up call stack
#1  0x1625 in main () at temp.c:11     gdb displays stack frame
(gdb) p i             Show us the value of i
```

```
$1 = 4231          gdb displays 4231
```

Oh dear! Looking at the code, we forgot to initialize i. We meant to put

```
...
main() {
  int i;

  i = 5;
  printf("This is my program\n");
...
```

but we left the i=5; line out. As we did not initialize i, it had whatever number happened to be in that area of memory when the program ran, which in this case happened to be 4231.

The gdb command displays the stack frame every time we go into or out of a function, even if we are using up and down to move around the call stack. This shows the name of the function and the values of its arguments, which helps us keep track of where we are and what is going on. (The stack is a storage area where the program stores information about the arguments passed to functions and where to go when it returns from a function call.)

2.6.3.3. Examining a Core File with gdb

A core file is basically a file which contains the complete state of the process when it crashed. In "the good old days", programmers had to print out hex listings of core files and sweat over machine code manuals, but now life is a bit easier. Incidentally, under FreeBSD and other 4.4BSD systems, a core file is called progname.core instead of just core, to make it clearer which program a core file belongs to.

To examine a core file, start up gdb in the usual way. Instead of typing break or run, type

```
(gdb) core progname.core
```

If the core file is not in the current directory, type dir /path/to/core/file first.

The debugger should display something like this:

```
% gdb progname
GDB is free software and you are welcome to distribute copies of it
 under certain conditions; type "show copying" to see the conditions.
There is absolutely no warranty for GDB; type "show warranty" for details.
GDB 4.13 (i386-unknown-freebsd), Copyright 1994 Free Software Foundation, Inc.
(gdb) core progname.core
Core was generated by `progname'.
Program terminated with signal 11, Segmentation fault.
Cannot access memory at address 0x7020796d.
#0  0x164a in bazz (anint=0x5) at temp.c:17
```

```
(gdb)
```

In this case, the program was called progname, so the core file is called progname.core. We can see that the program crashed due to trying to access an area in memory that was not available to it in a function called bazz.

Sometimes it is useful to be able to see how a function was called, as the problem could have occurred a long way up the call stack in a complex program. bt causes gdb to print out a back-trace of the call stack:

```
(gdb) bt
#0  0x164a in bazz (anint=0x5) at temp.c:17
#1  0xefbfd888 in end ()
#2  0x162c in main () at temp.c:11
(gdb)
```

The end() function is called when a program crashes; in this case, the bazz() function was called from main().

2.6.3.4. Attaching to a Running Program with gdb

One of the neatest features about gdb is that it can attach to a program that is already running. Of course, that requires sufficient permissions to do so. A common problem is stepping through a program that forks and wanting to trace the child, but the debugger will only trace the parent.

To do that, start up another gdb, use ps to find the process ID for the child, and do

```
(gdb) attach pid
```

in gdb, and then debug as usual.

For that to work well, the code that calls fork to create the child needs to do something like the following (courtesy of the gdb info pages):

```
...
if ((pid = fork()) < 0)     /* _Always_ check this */
   error();
else if (pid == 0) {      /* child */
   int PauseMode = 1;

   while (PauseMode)
      sleep(10);  /* Wait until someone attaches to us */
   ...
} else {         /* parent */
   ...
```

Now all that is needed is to attach to the child, set PauseMode to 0, and wait for the sleep() call to return!

2.7. Using Emacs as a Development Environment

2.7.1. Emacs

Emacs is a highly customizable editor-indeed, it has been customized to the point where it is more like an operating system than an editor! Many developers and sysadmins do in fact spend practically all their time working inside Emacs, leaving it only to log out.

It is impossible even to summarize everything Emacs can do here, but here are some of the features of interest to developers:

- Very powerful editor, allowing search-and-replace on both strings and regular expressions (patterns), jumping to start/end of block expression, etc, etc.
- Pull-down menus and online help.
- Language-dependent syntax highlighting and indentation.
- Completely customizable.
- You can compile and debug programs within Emacs.
- On a compilation error, you can jump to the offending line of source code.
- Friendly-ish front-end to the info program used for reading GNU hypertext documentation, including the documentation on Emacs itself.
- Friendly front-end to gdb, allowing you to look at the source code as you step through your program.

And doubtless many more that have been overlooked.

Emacs can be installed on FreeBSD using the editors/emacs port.

Once it is installed, start it up and do C-h t to read an Emacs tutorial-that means hold down control, press h, let go of control, and then press t. (Alternatively, you can use the mouse to select Emacs Tutorial from the Help menu.)

Although Emacs does have menus, it is well worth learning the key bindings, as it is much quicker when you are editing something to press a couple of keys than to try to find the mouse and then click on the right place. And, when you are talking to seasoned Emacs users, you will find they often casually throw around expressions like "M-x replace-s RET foo RET bar RET" so it is useful to know what they mean. And in any case, Emacs has far too many useful functions for them to all fit on the menu bars.

Fortunately, it is quite easy to pick up the key-bindings, as they are displayed next to the menu item. My advice is to use the menu item for, say, opening a file until you understand how it works and feel confident with it, then try doing C-x C-f. When you are happy with that, move on to another menu command.

If you cannot remember what a particular combination of keys does, select Describe Key from the Help menu and type it in-Emacs will tell you what it does. You can also use the Command Apropos menu item to find out all the commands which contain a particular word in them, with the key binding next to it.

By the way, the expression above means hold down the Meta key, press x, release the Meta key, type replace-s (short for replace-string-another feature of Emacs is that you can abbreviate commands), press the return key, type foo (the string you want replaced), press the return key, type bar (the string you want to replace foo with) and press return again. Emacs will then do the search-and-replace operation you have just requested.

If you are wondering what on earth Meta is, it is a special key that many UNIX® workstations have. Unfortunately, PC's do not have one, so it is usually alt (or if you are unlucky, the escape key).

Oh, and to get out of Emacs, do C-x C-c (that means hold down the control key, press x, press c and

release the control key). If you have any unsaved files open, Emacs will ask you if you want to save them. (Ignore the bit in the documentation where it says C-z is the usual way to leave Emacs-that leaves Emacs hanging around in the background, and is only really useful if you are on a system which does not have virtual terminals).

2.7.2. Configuring Emacs

Emacs does many wonderful things; some of them are built in, some of them need to be configured.

Instead of using a proprietary macro language for configuration, Emacs uses a version of Lisp specially adapted for editors, known as Emacs Lisp. Working with Emacs Lisp can be quite helpful if you want to go on and learn something like Common Lisp. Emacs Lisp has many features of Common Lisp, although it is considerably smaller (and thus easier to master).

The best way to learn Emacs Lisp is to download the Emacs Tutorial

However, there is no need to actually know any Lisp to get started with configuring Emacs, as I have included a sample .emacs, which should be enough to get you started. Just copy it into your home directory and restart Emacs if it is already running; it will read the commands from the file and (hopefully) give you a useful basic setup.

2.7.3. A Sample .emacs

Unfortunately, there is far too much here to explain it in detail; however there are one or two points worth mentioning.

- Everything beginning with a ; is a comment and is ignored by Emacs.
- In the first line, the -- Emacs-Lisp -- is so that we can edit .emacs itself within Emacs and get all the fancy features for editing Emacs Lisp. Emacs usually tries to guess this based on the filename, and may not get it right for .emacs.
- The tab key is bound to an indentation function in some modes, so when you press the tab key, it will indent the current line of code. If you want to put a tab character in whatever you are writing, hold the control key down while you are pressing the tab key.
- This file supports syntax highlighting for C, C++, Perl, Lisp and Scheme, by guessing the language from the filename.
- Emacs already has a pre-defined function called next-error. In a compilation output window, this allows you to move from one compilation error to the next by doing M-n; we define a complementary function, previous-error, that allows you to go to a previous error by doing M-p. The nicest feature of all is that C-c C-c will open up the source file in which the error occurred and jump to the appropriate line.
- We enable Emacs' s ability to act as a server, so that if you are doing something outside Emacs and you want to edit a file, you can just type in

  ```
  % emacsclient filename
  ```

  and then you can edit the file in your Emacs![2]

例 1. A Sample .emacs

```
;; -*-Emacs-Lisp-*-

;; This file is designed to be re-evaled; use the variable first-time
;; to avoid any problems with this.
(defvar first-time t
```

```
  "Flag signifying this is the first time that .emacs has been evaled")

;; Meta
(global-set-key "\M- " 'set-mark-command)
(global-set-key "\M-\C-h" 'backward-kill-word)
(global-set-key "\M-\C-r" 'query-replace)
(global-set-key "\M-r" 'replace-string)
(global-set-key "\M-g" 'goto-line)
(global-set-key "\M-h" 'help-command)

;; Function keys
(global-set-key [f1] 'manual-entry)
(global-set-key [f2] 'info)
(global-set-key [f3] 'repeat-complex-command)
(global-set-key [f4] 'advertised-undo)
(global-set-key [f5] 'eval-current-buffer)
(global-set-key [f6] 'buffer-menu)
(global-set-key [f7] 'other-window)
(global-set-key [f8] 'find-file)
(global-set-key [f9] 'save-buffer)
(global-set-key [f10] 'next-error)
(global-set-key [f11] 'compile)
(global-set-key [f12] 'grep)
(global-set-key [C-f1] 'compile)
(global-set-key [C-f2] 'grep)
(global-set-key [C-f3] 'next-error)
(global-set-key [C-f4] 'previous-error)
(global-set-key [C-f5] 'display-faces)
(global-set-key [C-f8] 'dired)
(global-set-key [C-f10] 'kill-compilation)

;; Keypad bindings
(global-set-key [up] "\C-p")
(global-set-key [down] "\C-n")
(global-set-key [left] "\C-b")
(global-set-key [right] "\C-f")
(global-set-key [home] "\C-a")
(global-set-key [end] "\C-e")
(global-set-key [prior] "\M-v")
(global-set-key [next] "\C-v")
(global-set-key [C-up] "\M-\C-b")
(global-set-key [C-down] "\M-\C-f")
```

```
(global-set-key [C-left] "\M-b")
(global-set-key [C-right] "\M-f")
(global-set-key [C-home] "\M-<")
(global-set-key [C-end] "\M->")
(global-set-key [C-prior] "\M-<")
(global-set-key [C-next] "\M->")

;; Mouse
(global-set-key [mouse-3] 'imenu)

;; Misc
(global-set-key [C-tab] "\C-q\t")   ; Control tab quotes a tab.
(setq backup-by-copying-when-mismatch t)

;; Treat 'y' or <CR> as yes, 'n' as no.
(fset 'yes-or-no-p 'y-or-n-p)
(define-key query-replace-map [return] 'act)
(define-key query-replace-map [?\C-m] 'act)

;; Load packages
(require 'desktop)
(require 'tar-mode)

;; Pretty diff mode
(autoload 'ediff-buffers "ediff" "Intelligent Emacs interface to diff" t)
(autoload 'ediff-files "ediff" "Intelligent Emacs interface to diff" t)
(autoload 'ediff-files-remote "ediff"
 "Intelligent Emacs interface to diff")

(if first-time
   (setq auto-mode-alist
    (append '(("\\.cpp$" . c++-mode)
        ("\\.hpp$" . c++-mode)
        ("\\.lsp$" . lisp-mode)
        ("\\.scm$" . scheme-mode)
        ("\\.pl$" . perl-mode)
        ) auto-mode-alist)))

;; Auto font lock mode
(defvar font-lock-auto-mode-list
 (list 'c-mode 'c++-mode 'c++-c-mode 'emacs-lisp-mode 'lisp-mode 'perl-mode
'scheme-mode)
 "List of modes to always start in font-lock-mode")
```

```
(defvar font-lock-mode-keyword-alist
 '((c++-c-mode . c-font-lock-keywords)
   (perl-mode . perl-font-lock-keywords))
 "Associations between modes and keywords")

(defun font-lock-auto-mode-select ()
 "Automatically select font-lock-mode if the current major mode is in font-lock-auto-mode-list"
 (if (memq major-mode font-lock-auto-mode-list)
    (progn
   (font-lock-mode t))
   )
 )

(global-set-key [M-f1] 'font-lock-fontify-buffer)

;; New dabbrev stuff
;(require 'new-dabbrev)
(setq dabbrev-always-check-other-buffers t)
(setq dabbrev-abbrev-char-regexp "\\sw\\|\\s_")
(add-hook 'emacs-lisp-mode-hook
    '(lambda ()
       (set (make-local-variable 'dabbrev-case-fold-search) nil)
       (set (make-local-variable 'dabbrev-case-replace) nil)))
(add-hook 'c-mode-hook
    '(lambda ()
       (set (make-local-variable 'dabbrev-case-fold-search) nil)
       (set (make-local-variable 'dabbrev-case-replace) nil)))
(add-hook 'text-mode-hook
    '(lambda ()
       (set (make-local-variable 'dabbrev-case-fold-search) t)
       (set (make-local-variable 'dabbrev-case-replace) t)))

;; C++ and C mode...
(defun my-c++-mode-hook ()
 (setq tab-width 4)
 (define-key c++-mode-map "\C-m" 'reindent-then-newline-and-indent)
 (define-key c++-mode-map "\C-ce" 'c-comment-edit)
 (setq c++-auto-hungry-initial-state 'none)
 (setq c++-delete-function 'backward-delete-char)
 (setq c++-tab-always-indent t)
 (setq c-indent-level 4)
```

```
  (setq c-continued-statement-offset 4)
  (setq c++-empty-arglist-indent 4))

(defun my-c-mode-hook ()
  (setq tab-width 4)
  (define-key c-mode-map "\C-m" 'reindent-then-newline-and-indent)
  (define-key c-mode-map "\C-ce" 'c-comment-edit)
  (setq c-auto-hungry-initial-state 'none)
  (setq c-delete-function 'backward-delete-char)
  (setq c-tab-always-indent t)
;; BSD-ish indentation style
  (setq c-indent-level 4)
  (setq c-continued-statement-offset 4)
  (setq c-brace-offset -4)
  (setq c-argdecl-indent 0)
  (setq c-label-offset -4))

;; Perl mode
(defun my-perl-mode-hook ()
  (setq tab-width 4)
  (define-key c++-mode-map "\C-m" 'reindent-then-newline-and-indent)
  (setq perl-indent-level 4)
  (setq perl-continued-statement-offset 4))

;; Scheme mode...
(defun my-scheme-mode-hook ()
  (define-key scheme-mode-map "\C-m" 'reindent-then-newline-and-indent))

;; Emacs-Lisp mode...
(defun my-lisp-mode-hook ()
  (define-key lisp-mode-map "\C-m" 'reindent-then-newline-and-indent)
  (define-key lisp-mode-map "\C-i" 'lisp-indent-line)
  (define-key lisp-mode-map "\C-j" 'eval-print-last-sexp))

;; Add all of the hooks...
(add-hook 'c++-mode-hook 'my-c++-mode-hook)
(add-hook 'c-mode-hook 'my-c-mode-hook)
(add-hook 'scheme-mode-hook 'my-scheme-mode-hook)
(add-hook 'emacs-lisp-mode-hook 'my-lisp-mode-hook)
(add-hook 'lisp-mode-hook 'my-lisp-mode-hook)
(add-hook 'perl-mode-hook 'my-perl-mode-hook)
```

```
;; Complement to next-error
(defun previous-error (n)
 "Visit previous compilation error message and corresponding source code."
 (interactive "p")
 (next-error (- n)))

;; Misc...
(transient-mark-mode 1)
(setq mark-even-if-inactive t)
(setq visible-bell nil)
(setq next-line-add-newlines nil)
(setq compile-command "make")
(setq suggest-key-bindings nil)
(put 'eval-expression 'disabled nil)
(put 'narrow-to-region 'disabled nil)
(put 'set-goal-column 'disabled nil)
(if (>= emacs-major-version 21)
   (setq show-trailing-whitespace t))

;; Elisp archive searching
(autoload 'format-lisp-code-directory "lispdir" nil t)
(autoload 'lisp-dir-apropos "lispdir" nil t)
(autoload 'lisp-dir-retrieve "lispdir" nil t)
(autoload 'lisp-dir-verify "lispdir" nil t)

;; Font lock mode
(defun my-make-face (face color &optional bold)
 "Create a face from a color and optionally make it bold"
 (make-face face)
 (copy-face 'default face)
 (set-face-foreground face color)
 (if bold (make-face-bold face))
 )

(if (eq window-system 'x)
   (progn
    (my-make-face 'blue "blue")
    (my-make-face 'red "red")
    (my-make-face 'green "dark green")
    (setq font-lock-comment-face 'blue)
    (setq font-lock-string-face 'bold)
    (setq font-lock-type-face 'bold)
```

```
    (setq font-lock-keyword-face 'bold)
    (setq font-lock-function-name-face 'red)
    (setq font-lock-doc-string-face 'green)
    (add-hook 'find-file-hooks 'font-lock-auto-mode-select)

    (setq baud-rate 1000000)
    (global-set-key "\C-cmm" 'menu-bar-mode)
    (global-set-key "\C-cms" 'scroll-bar-mode)
    (global-set-key [backspace] 'backward-delete-char)
            ;     (global-set-key [delete] 'delete-char)
    (standard-display-european t)
    (load-library "iso-transl")))

;; X11 or PC using direct screen writes
(if window-system
   (progn
    ;;     (global-set-key [M-f1] 'hilit-repaint-command)
    ;;     (global-set-key [M-f2] [?\C-u M-f1])
    (setq hilit-mode-enable-list
      '(not text-mode c-mode c++-mode emacs-lisp-mode lisp-mode
        scheme-mode)
      hilit-auto-highlight nil
      hilit-auto-rehighlight 'visible
      hilit-inhibit-hooks nil
      hilit-inhibit-rebinding t)
    (require 'hilit19)
    (require 'paren))
 (setq baud-rate 2400)       ; For slow serial connections
 )

;; TTY type terminal
(if (and (not window-system)
    (not (equal system-type 'ms-dos)))
   (progn
    (if first-time
    (progn
      (keyboard-translate ?\C-h ?\C-?)
      (keyboard-translate ?\C-? ?\C-h)))))

;; Under UNIX
(if (not (equal system-type 'ms-dos))
   (progn
```

```
    (if first-time
    (server-start))))

;; Add any face changes here
(add-hook 'term-setup-hook 'my-term-setup-hook)
(defun my-term-setup-hook ()
 (if (eq window-system 'pc)
    (progn
;;  (set-face-background 'default "red")
   )))

;; Restore the "desktop" - do this as late as possible
(if first-time
   (progn
    (desktop-load-default)
    (desktop-read)))

;; Indicate that this file has been read at least once
(setq first-time nil)

;; No need to debug anything now

(setq debug-on-error nil)

;; All done
(message "All done, %s%s" (user-login-name) ".")
```

2.7.4. Extending the Range of Languages Emacs Understands

Now, this is all very well if you only want to program in the languages already catered for in .emacs (C, C++, Perl, Lisp and Scheme), but what happens if a new language called "whizbang" comes out, full of exciting features?

The first thing to do is find out if whizbang comes with any files that tell Emacs about the language. These usually end in .el, short for "Emacs Lisp". For example, if whizbang is a FreeBSD port, we can locate these files by doing

```
% find /usr/ports/lang/whizbang -name "*.el" -print
```

and install them by copying them into the Emacs site Lisp directory. On FreeBSD, this is /usr/local/shared/emacs/site-lisp.

So for example, if the output from the find command was

```
/usr/ports/lang/whizbang/work/misc/whizbang.el
```

we would do

```
# cp /usr/ports/lang/whizbang/work/misc/whizbang.el /usr/local/shared/emacs/site-lisp
```

Next, we need to decide what extension whizbang source files have. Let us say for the sake of argument that they all end in .wiz. We need to add an entry to our .emacs to make sure Emacs will be able to use the information in whizbang.el.

Find the auto-mode-alist entry in .emacs and add a line for whizbang, such as:

```
...
("\\.lsp$" . lisp-mode)
("\\.wiz$" . whizbang-mode)
("\\.scm$" . scheme-mode)
...
```

This means that Emacs will automatically go into whizbang-mode when you edit a file ending in .wiz.

Just below this, you will find the font-lock-auto-mode-list entry. Add whizbang-mode to it like so:

```
;; Auto font lock mode
(defvar font-lock-auto-mode-list
  (list 'c-mode 'c++-mode 'c++-c-mode 'emacs-lisp-mode 'whizbang-mode 'lisp-mode 'perl-
mode 'scheme-mode)
  "List of modes to always start in font-lock-mode")
```

This means that Emacs will always enable font-lock-mode (ie syntax highlighting) when editing a .wiz file.

And that is all that is needed. If there is anything else you want done automatically when you open up .wiz, you can add a whizbang-mode hook (see my-scheme-mode-hook for a simple example that adds auto-indent).

2.8. Further Reading

For information about setting up a development environment for contributing fixes to FreeBSD itself, please see development(7).

- Brian Harvey and Matthew Wright Simply Scheme MIT 1994. ISBN 0-262-08226-8
- Randall Schwartz Learning Perl O’ Reilly 1993 ISBN 1-56592-042-2
- Patrick Henry Winston and Berthold Klaus Paul Horn Lisp (3rd Edition) Addison-Wesley 1989 ISBN 0-201-08319-1
- Brian W. Kernighan and Rob Pike The Unix Programming Environment Prentice-Hall 1984 ISBN 0-13-937681-X
- Brian W. Kernighan and Dennis M. Ritchie The C Programming Language (2nd Edition) Prentice-Hall 1988 ISBN 0-13-110362-8
- Bjarne Stroustrup The C++ Programming Language Addison-Wesley 1991 ISBN 0-201-53992-6
- W. Richard Stevens Advanced Programming in the Unix Environment Addison-Wesley 1992 ISBN 0-201-56317-7

- W. Richard Stevens Unix Network Programming Prentice-Hall 1990 ISBN 0-13-949876-1

[1] They do not use the MAKEFILE form as block capitals are often used for documentation files like README.
[2] Many Emacs users set their EDITOR environment to emacsclient so this happens every time they need to edit a file.

Chapter 3. Secure Programming

3.1. Synopsis

This chapter describes some of the security issues that have plagued UNIX® programmers for decades and some of the new tools available to help programmers avoid writing exploitable code.

3.2. Secure Design Methodology

Writing secure applications takes a very scrutinous and pessimistic outlook on life. Applications should be run with the principle of "least privilege" so that no process is ever running with more than the bare minimum access that it needs to accomplish its function. Previously tested code should be reused whenever possible to avoid common mistakes that others may have already fixed.

One of the pitfalls of the UNIX® environment is how easy it is to make assumptions about the sanity of the environment. Applications should never trust user input (in all its forms), system resources, inter-process communication, or the timing of events. UNIX® processes do not execute synchronously so logical operations are rarely atomic.

3.3. Buffer Overflows

Buffer Overflows have been around since the very beginnings of the von Neumann 1 architecture. They first gained widespread notoriety in 1988 with the Morris Internet worm. Unfortunately, the same basic attack remains effective today. By far the most common type of buffer overflow attack is based on corrupting the stack.

Most modern computer systems use a stack to pass arguments to procedures and to store local variables. A stack is a last in first out (LIFO) buffer in the high memory area of a process image. When a program invokes a function a new "stack frame" is created. This stack frame consists of the arguments passed to the function as well as a dynamic amount of local variable space. The "stack pointer" is a register that holds the current location of the top of the stack. Since this value is constantly changing as new values are pushed onto the top of the stack, many implementations also provide a "frame pointer" that is located near the beginning of a stack frame so that local variables can more easily be addressed relative to this value. 1 The return address for function calls is also stored on the stack, and this is the cause of stack-overflow exploits since overflowing a local variable in a function can overwrite the return address of that function, potentially allowing a malicious user to execute any code he or she wants.

Although stack-based attacks are by far the most common, it would also be possible to overrun the stack with a heap-based (malloc/free) attack.

The C programming language does not perform automatic bounds checking on arrays or pointers as many other languages do. In addition, the standard C library is filled with a handful of very dangerous functions.

strcpy(char *dest, const char *src)	May overflow the dest buffer
strcat(char *dest, const char *src)	May overflow the dest buffer
getwd(char *buf)	May overflow the buf buffer
gets(char *s)	May overflow the s buffer
[vf]scanf(const char *format, ⋯)	May overflow its arguments.
realpath(char *path, char resolved_path[])	May overflow the path buffer
[v]sprintf(char *str, const char *format, ⋯)	May overflow the str buffer.

3.3.1. Example Buffer Overflow

The following example code contains a buffer overflow designed to overwrite the return address and skip the instruction immediately following the function call. (Inspired by 4)

```
#include <stdio.h>

void manipulate(char *buffer) {
 char newbuffer[80];
 strcpy(newbuffer,buffer);
}

int main() {
 char ch,buffer[4096];
 int i=0;

 while ((buffer[i++] = getchar()) != '\n') {};

 i=1;
 manipulate(buffer);
 i=2;
 printf("The value of i is : %d\n",i);
 return 0;
}
```

Let us examine what the memory image of this process would look like if we were to input 160 spaces into our little program before hitting return.

Obviously more malicious input can be devised to execute actual compiled instructions (such as exec(/bin/sh)).

3.3.2. Avoiding Buffer Overflows

The most straightforward solution to the problem of stack-overflows is to always use length restricted memory and string copy functions. strncpy and strncat are part of the standard C library. These functions accept a length value as a parameter which should be no larger than the size of the destination buffer. These functions will then copy up to 'length' bytes from the source to the destination. However there are a number of problems with these functions. Neither function guarantees NUL termination if the size of the input buffer is as large as the destination. The length parameter is also used inconsistently between strncpy and strncat so it is easy for programmers to get confused as to their proper usage. There is also a significant performance loss compared to strcpy when copying a short string into a large buffer since strncpy NUL fills up the size specified.

Another memory copy implementation exists to get around these problems. The strlcpy and strlcat functions guarantee that they will always null terminate the destination string when given a non-zero length argument.

3.3.2.1. Compiler based run-time bounds checking

Unfortunately there is still a very large assortment of code in public use which blindly copies memory around without using any of the bounded copy routines we just discussed. Fortunately, there is a way to help prevent such attacks - run-time bounds checking, which is implemented by

several C/C++ compilers.

ProPolice is one such compiler feature, and is integrated into gcc(1) versions 4.1 and later. It replaces and extends the earlier StackGuard gcc(1) extension.

ProPolice helps to protect against stack-based buffer overflows and other attacks by laying pseudo-random numbers in key areas of the stack before calling any function. When a function returns, these "canaries" are checked and if they are found to have been changed the executable is immediately aborted. Thus any attempt to modify the return address or other variable stored on the stack in an attempt to get malicious code to run is unlikely to succeed, as the attacker would have to also manage to leave the pseudo-random canaries untouched.

Recompiling your application with ProPolice is an effective means of stopping most buffer-overflow attacks, but it can still be compromised.

3.3.2.2. Library based run-time bounds checking

Compiler-based mechanisms are completely useless for binary-only software for which you cannot recompile. For these situations there are a number of libraries which re-implement the unsafe functions of the C-library (strcpy, fscanf, getwd, etc..) and ensure that these functions can never write past the stack pointer.

- libsafe
- libverify
- libparanoia

Unfortunately these library-based defenses have a number of shortcomings. These libraries only protect against a very small set of security related issues and they neglect to fix the actual problem. These defenses may fail if the application was compiled with -fomit-frame-pointer. Also, the LD_PRELOAD and LD_LIBRARY_PATH environment variables can be overwritten/unset by the user.

3.4. SetUID issues

There are at least 6 different IDs associated with any given process. Because of this you have to be very careful with the access that your process has at any given time. In particular, all seteuid applications should give up their privileges as soon as it is no longer required.

The real user ID can only be changed by a superuser process. The login program sets this when a user initially logs in and it is seldom changed.

The effective user ID is set by the exec() functions if a program has its seteuid bit set. An application can call seteuid() at any time to set the effective user ID to either the real user ID or the saved set-user-ID. When the effective user ID is set by exec() functions, the previous value is saved in the saved set-user-ID.

3.5. Limiting your program’s environment

The traditional method of restricting a process is with the chroot() system call. This system call changes the root directory from which all other paths are referenced for a process and any child processes. For this call to succeed the process must have execute (search) permission on the directory being referenced. The new environment does not actually take effect until you chdir() into your new environment. It should also be noted that a process can easily break out of a chroot environment if it has root privilege. This could be accomplished by creating device nodes to read kernel memory, attaching a debugger to a process outside of the chroot(8) environment, or in many other creative ways.

The behavior of the chroot() system call can be controlled somewhat with the kern.chroot_allow_open_directories sysctl variable. When this value is set to 0, chroot() will fail with EPERM if there are any directories open. If set to the default value of 1, then chroot() will fail with EPERM if there are any directories open and the process is already subject to a chroot() call.

For any other value, the check for open directories will be bypassed completely.

3.5.1. FreeBSD’ s jail functionality

The concept of a Jail extends upon the chroot() by limiting the powers of the superuser to create a true `virtual server'. Once a prison is set up all network communication must take place through the specified IP address, and the power of "root privilege" in this jail is severely constrained.

While in a prison, any tests of superuser power within the kernel using the suser() call will fail. However, some calls to suser() have been changed to a new interface suser_xxx(). This function is responsible for recognizing or denying access to superuser power for imprisoned processes.

A superuser process within a jailed environment has the power to:

- Manipulate credential with setuid, seteuid, setgid, setegid, setgroups, setreuid, setregid, setlogin
- Set resource limits with setrlimit
- Modify some sysctl nodes (kern.hostname)
- chroot()
- Set flags on a vnode: chflags, fchflags
- Set attributes of a vnode such as file permission, owner, group, size, access time, and modification time.
- Bind to privileged ports in the Internet domain (ports < 1024)

Jail is a very useful tool for running applications in a secure environment but it does have some shortcomings. Currently, the IPC mechanisms have not been converted to the suser_xxx so applications such as MySQL cannot be run within a jail. Superuser access may have a very limited meaning within a jail, but there is no way to specify exactly what "very limited" means.

3.5.2. POSIX®.1e Process Capabilities

POSIX® has released a working draft that adds event auditing, access control lists, fine grained privileges, information labeling, and mandatory access control.

This is a work in progress and is the focus of the TrustedBSD project. Some of the initial work has been committed to FreeBSD-CURRENT (cap_set_proc(3)).

3.6. Trust

An application should never assume that anything about the users environment is sane. This includes (but is certainly not limited to): user input, signals, environment variables, resources, IPC, mmaps, the filesystem working directory, file descriptors, the # of open files, etc.

You should never assume that you can catch all forms of invalid input that a user might supply. Instead, your application should use positive filtering to only allow a specific subset of inputs that you deem safe. Improper data validation has been the cause of many exploits, especially with CGI scripts on the world wide web. For filenames you need to be extra careful about paths ("../", "/"), symbolic links, and shell escape characters.

Perl has a really cool feature called "Taint" mode which can be used to prevent scripts from using data derived outside the program in an unsafe way. This mode will check command line arguments, environment variables, locale information, the results of certain syscalls (readdir(), readlink(), getpwxxx()), and all file input.

3.7. Race Conditions

A race condition is anomalous behavior caused by the unexpected dependence on the relative

timing of events. In other words, a programmer incorrectly assumed that a particular event would always happen before another.

Some of the common causes of race conditions are signals, access checks, and file opens. Signals are asynchronous events by nature so special care must be taken in dealing with them. Checking access with access(2) then open(2) is clearly non-atomic. Users can move files in between the two calls. Instead, privileged applications should seteuid() and then call open() directly. Along the same lines, an application should always set a proper umask before open() to obviate the need for spurious chmod() calls.

Chapter 4. Localization and Internationalization - L10N and I18N

4.1. Programming I18N Compliant Applications

To make your application more useful for speakers of other languages, we hope that you will program I18N compliant. The GNU gcc compiler and GUI libraries like QT and GTK support I18N through special handling of strings. Making a program I18N compliant is very easy. It allows contributors to port your application to other languages quickly. Refer to the library specific I18N documentation for more details.

In contrast with common perception, I18N compliant code is easy to write. Usually, it only involves wrapping your strings with library specific functions. In addition, please be sure to allow for wide or multibyte character support.

4.1.1. A Call to Unify the I18N Effort

It has come to our attention that the individual I18N/L10N efforts for each country has been repeating each others' efforts. Many of us have been reinventing the wheel repeatedly and inefficiently. We hope that the various major groups in I18N could congregate into a group effort similar to the Core Team’ s responsibility.

Currently, we hope that, when you write or port I18N programs, you would send it out to each country’ s related FreeBSD mailing list for testing. In the future, we hope to create applications that work in all the languages out-of-the-box without dirty hacks.

The FreeBSD internationalization 郵遞論壇 has been established. If you are an I18N/L10N developer, please send your comments, ideas, questions, and anything you deem related to it.

4.1.2. Perl and Python

Perl and Python have I18N and wide character handling libraries. Please use them for I18N compliance.

4.2. Localized Messages with POSIX.1 Native Language Support (NLS)

Beyond the basic I18N functions, like supporting various input encodings or supporting national conventions, such as the different decimal separators, at a higher level of I18N, it is possible to localize the messages written to the output by the various programs. A common way of doing this is using the POSIX.1 NLS functions, which are provided as a part of the FreeBSD base system.

4.2.1. Organizing Localized Messages into Catalog Files

POSIX.1 NLS is based on catalog files, which contain the localized messages in the desired encoding. The messages are organized into sets and each message is identified by an integer number in the containing set. The catalog files are conventionally named after the locale they contain localized messages for, followed by the .msg extension. For instance, the Hungarian messages for ISO8859-2 encoding should be stored in a file called hu_HU.ISO8859-2.

These catalog files are common text files that contain the numbered messages. It is possible to write comments by starting the line with a $ sign. Set boundaries are also separated by special comments, where the keyword set must directly follow the $ sign. The set keyword is then followed by the set number. For example:

```
$set 1
```

The actual message entries start with the message number and followed by the localized message. The well-known modifiers from printf(3) are accepted:

```
15 "File not found: %s\n"
```

The language catalog files have to be compiled into a binary form before they can be opened from the program. This conversion is done with the gencat(1) utility. Its first argument is the filename of the compiled catalog and its further arguments are the input catalogs. The localized messages can also be organized into more catalog files and then all of them can be processed with gencat(1).

4.2.2. Using the Catalog Files from the Source Code

Using the catalog files is simple. To use the related functions, nl_types.h must be included. Before using a catalog, it has to be opened with catopen(3). The function takes two arguments. The first parameter is the name of the installed and compiled catalog. Usually, the name of the program is used, such as grep. This name will be used when looking for the compiled catalog file. The catopen(3) call looks for this file in /usr/shared/nls/locale/catname and in /usr/local/shared/nls/locale/catname, where locale is the locale set and catname is the catalog name being discussed. The second parameter is a constant, which can have two values:

- NL_CAT_LOCALE, which means that the used catalog file will be based on LC_MESSAGES.
- 0, which means that LANG has to be used to open the proper catalog.

The catopen(3) call returns a catalog identifier of type nl_catd. Please refer to the manual page for a list of possible returned error codes.

After opening a catalog catgets(3) can be used to retrieve a message. The first parameter is the catalog identifier returned by catopen(3), the second one is the number of the set, the third one is the number of the messages, and the fourth one is a fallback message, which will be returned if the requested message cannot be retrieved from the catalog file.

After using the catalog file, it must be closed by calling catclose(3), which has one argument, the catalog id.

4.2.3. A Practical Example

The following example will demonstrate an easy solution on how to use NLS catalogs in a flexible way.

The below lines need to be put into a common header file of the program, which is included into all source files where localized messages are necessary:

```
#ifdef WITHOUT_NLS
#define getstr(n)    nlsstr[n]
#else
#include nl_types.h

extern nl_catd      catalog;
#define getstr(n)    catgets(catalog, 1, n, nlsstr[n])
#endif

extern char    *nlsstr[];
```

Next, put these lines into the global declaration part of the main source file:

```
#ifndef WITHOUT_NLS
#include nl_types.h
nl_catd  catalog;
#endif

/*
 * Default messages to use when NLS is disabled or no catalog
 * is found.
 */
char    *nlsstr[] = {
      "",
/* 1*/  "some random message",
/* 2*/  "some other message"
};
```

Next come the real code snippets, which open, read, and close the catalog:

```
#ifndef WITHOUT_NLS
   catalog = catopen("myapp", NL_CAT_LOCALE);
#endif

...

printf(getstr(1));

...

#ifndef WITHOUT_NLS
   catclose(catalog);
#endif
```

4.2.3.1. Reducing Strings to Localize

There is a good way of reducing the strings that need to be localized by using libc error messages. This is also useful to just avoid duplication and provide consistent error messages for the common errors that can be encountered by a great many of programs.

First, here is an example that does not use libc error messages:

```
#include err.h
...
if (!S_ISDIR(st.st_mode))
```

```
    errx(1, "argument is not a directory");
```

This can be transformed to print an error message by reading errno and printing an error message accordingly:

```
#include err.h
#include errno.h
...
if (!S_ISDIR(st.st_mode)) {
    errno = ENOTDIR;
    err(1, NULL);
}
```

In this example, the custom string is eliminated, thus translators will have less work when localizing the program and users will see the usual "Not a directory" error message when they encounter this error. This message will probably seem more familiar to them. Please note that it was necessary to include errno.h in order to directly access errno.

It is worth to note that there are cases when errno is set automatically by a preceding call, so it is not necessary to set it explicitly:

```
#include err.h
...
if ((p = malloc(size)) == NULL)
    err(1, NULL);
```

4.2.4. Making use of bsd.nls.mk

Using the catalog files requires few repeatable steps, such as compiling the catalogs and installing them to the proper location. In order to simplify this process even more, bsd.nls.mk introduces some macros. It is not necessary to include bsd.nls.mk explicitly, it is pulled in from the common Makefiles, such as bsd.prog.mk or bsd.lib.mk.

Usually it is enough to define NLSNAME, which should have the catalog name mentioned as the first argument of catopen(3) and list the catalog files in NLS without their .msg extension. Here is an example, which makes it possible to to disable NLS when used with the code examples before. The WITHOUT_NLS make(1) variable has to be defined in order to build the program without NLS support.

```
.if !defined(WITHOUT_NLS)
NLS=    es_ES.ISO8859-1
NLS+=   hu_HU.ISO8859-2
NLS+=   pt_BR.ISO8859-1
.else
CFLAGS+=    -DWITHOUT_NLS
.endif
```

Conventionally, the catalog files are placed under the nls subdirectory and this is the default behavior of bsd.nls.mk. It is possible, though to override the location of the catalogs with the

NLSSRCDIR make(1) variable. The default name of the precompiled catalog files also follow the naming convention mentioned before. It can be overridden by setting the NLSNAME variable. There are other options to fine tune the processing of the catalog files but usually it is not needed, thus they are not described here. For further information on bsd.nls.mk, please refer to the file itself, it is short and easy to understand.

Chapter 5. Source Tree Guidelines and Policies

This chapter documents various guidelines and policies in force for the FreeBSD source tree.

5.1. Style Guidelines

Consistent coding style is extremely important, particularly with large projects like FreeBSD. Code should follow the FreeBSD coding styles described in style(9) and style.Makefile(5).

5.2. MAINTAINER on Makefiles

If a particular portion of the FreeBSD src/ distribution is being maintained by a person or group of persons, this is communicated through an entry in src/MAINTAINERS. Maintainers of ports within the Ports Collection express their maintainership to the world by adding a MAINTAINER line to the Makefile of the port in question:

```
MAINTAINER= email-addresses
```

For other parts of the repository, or for sections not listed as having a maintainer, or when you are unsure who the active maintainer is, try looking at the recent commit history of the relevant parts of the source tree. It is quite often the case that a maintainer is not explicitly named, but the people who are actively working in a part of the source tree for, say, the last couple of years are interested in reviewing changes. Even if this is not specifically mentioned in the documentation or the source itself, asking for a review as a form of courtesy is a very reasonable thing to do.

The role of the maintainer is as follows:

- The maintainer owns and is responsible for that code. This means that he or she is responsible for fixing bugs and answering problem reports pertaining to that piece of the code, and in the case of contributed software, for tracking new versions, as appropriate.
- Changes to directories which have a maintainer defined shall be sent to the maintainer for review before being committed. Only if the maintainer does not respond for an unacceptable period of time, to several emails, will it be acceptable to commit changes without review by the maintainer. However, it is suggested that you try to have the changes reviewed by someone else if at all possible.
- It is of course not acceptable to add a person or group as maintainer unless they agree to assume this duty. On the other hand it does not have to be a committer and it can easily be a group of people.

5.3. Contributed Software

Some parts of the FreeBSD distribution consist of software that is actively being maintained outside the FreeBSD project. For historical reasons, we call this contributed software. Some examples are sendmail, gcc and patch.

Over the last couple of years, various methods have been used in dealing with this type of software and all have some number of advantages and drawbacks. No clear winner has emerged.

Since this is the case, after some debate one of these methods has been selected as the "official" method and will be required for future imports of software of this kind. Furthermore, it is strongly suggested that existing contributed software converge on this model over time, as it has significant advantages over the old method, including the ability to easily obtain diffs relative to the "official" versions of the source by everyone (even without direct repository access). This will make it significantly easier to return changes to the primary developers of the contributed software.

Ultimately, however, it comes down to the people actually doing the work. If using this model is particularly unsuited to the package being dealt with, exceptions to these rules may be granted only with the approval of the core team and with the general consensus of the other developers. The ability to maintain the package in the future will be a key issue in the decisions.

Because it makes it harder to import future versions minor, trivial and/or cosmetic changes are strongly discouraged on files that are still tracking the vendor branch.

5.3.1. Vendor Imports with SVN

This section describes the vendor import procedure with Subversion in details.

1. Preparing the Tree

   If this is your first import after the switch to SVN, you will have to flatten and clean up the vendor tree, and bootstrap merge history in the main tree. If not, you can safely omit this step.

   During the conversion from CVS to SVN, vendor branches were imported with the same layout as the main tree. For example, the foo vendor sources ended up in vendor/foo/dist/contrib/foo, but it is pointless and rather inconvenient. What we really want is to have the vendor source directly in vendor/foo/dist, like this:

   ```
   % cd vendor/foo/dist/contrib/foo
   % svn move $(svn list) ../..
   % cd ../..
   % svn remove contrib
   % svn propdel -R svn:mergeinfo
   % svn commit
   ```

   Note that, the propdel bit is necessary because starting with 1.5, Subversion will automatically add svn:mergeinfo to any directory you copy or move. In this case, you will not need this information, since you are not going to merge anything from the tree you deleted.

   You may want to flatten the tags as well. The procedure is exactly the same. If you do this, put off the commit until the end.

   Check the dist tree and perform any cleanup that is deemed to be necessary. You may want to disable keyword expansion, as it makes no sense on unmodified vendor code. In some cases, it can be even be harmful.

   ```
   % svn propdel svn:keywords -R .
   % svn commit
   ```

   Bootstrapping of svn:mergeinfo on the target directory (in the main tree) to the revision that corresponds to the last change was made to the vendor tree prior to importing new sources is also needed:

   ```
   % cd head/contrib/foo
   % svn merge --record-only ^/vendor/foo/dist@12345678 .
   ```

```
% svn commit
```

With some shells, the ^ in the above command may need to be escaped with a backslash.

2. Importing New Sources

   Prepare a full, clean tree of the vendor sources. With SVN, we can keep a full distribution in the vendor tree without bloating the main tree. Import everything but merge only what is needed.

   Note that you will need to add any files that were added since the last vendor import, and remove any that were removed. To facilitate this, you should prepare sorted lists of the contents of the vendor tree and of the sources you are about to import:

   ```
   % cd vendor/foo/dist
   % svn list -R | grep -v '/$' | sort > ../old
   % cd ../foo-9.9
   % find . -type f | cut -c 3- | sort > ../new
   ```

   With these two files, the following command will list removed files (files only in old):

   ```
   % comm -23 ../old ../new
   ```

   While the command below will list added files (files only in new):

   ```
   % comm -13 ../old ../new
   ```

   Let us put this together:

   ```
   % cd vendor/foo/foo-9.9
   % tar cf - . | tar xf - -C ../dist
   % cd ../dist
   % comm -23 ../old ../new | xargs svn remove
   % comm -13 ../old ../new | xargs svn add
   ```

   If there are new directories in the new distribution, the last command will fail. You will have to add the directories, and run it again. Conversely, if any directories were removed, you will have to remove them manually.

   Check properties on any new files:

   - All text files should have svn:eol-style set to native.
   - All binary files should have svn:mime-type set to application/octet-stream, unless there is a more appropriate media type.
   - Executable files should have svn:executable set to *.
   - There should be no other properties on any file in the tree.

   You are ready to commit, but you should first check the output of svn

stat and svn diff to make sure everything is in order.

Once you have committed the new vendor release, you should tag it for future reference. The best and quickest way is to do it directly in the repository:

```
% svn copy ^/vendor/foo/dist svn_base/vendor/foo/9.9
```

To get the new tag, you can update your working copy of vendor/foo.

If you choose to do the copy in the checkout instead, do not forget to remove the generated svn:mergeinfo as described above.

3. Merging to -HEAD

   After you have prepared your import, it is time to merge. Option --accept=postpone tells SVN not to handle merge conflicts yet, because they will be taken care of manually:

   ```
   % cd head/contrib/foo
   % svn update
   % svn merge --accept=postpone ^/vendor/foo/dist
   ```

   Resolve any conflicts, and make sure that any files that were added or removed in the vendor tree have been properly added or removed in the main tree. It is always a good idea to check differences against the vendor branch:

   ```
   % svn diff --no-diff-deleted --old=^/vendor/foo/dist --new=.
   ```

   --no-diff-deleted tells SVN not to check files that are in the vendor tree but not in the main tree.

   With SVN, there is no concept of on or off the vendor branch. If a file that previously had local modifications no longer does, just remove any left-over cruft, such as FreeBSD version tags, so it no longer shows up in diffs against the vendor tree.

   If any changes are required for the world to build with the new sources, make them now - and test until you are satisfied that everything build and runs correctly.

4. Commit

   Now, you are ready to commit. Make sure you get everything in one go. Ideally, you would have done all steps in a clean tree, in which case you can just commit from the top of that tree. That is the best way to avoid surprises. If you do it properly, the tree will move atomically from a consistent state with the old code to a consistent state with the new code.

5.4. Encumbered Files

It might occasionally be necessary to include an encumbered file in the FreeBSD source tree. For example, if a device requires a small piece of binary code to be loaded to it before the device will operate, and we do not have the source to that code, then the binary file is said to be encumbered. The following policies apply to including encumbered files in the FreeBSD source tree.

1. Any file which is interpreted or executed by the system CPU(s) and not in source format is encumbered.
2. Any file with a license more restrictive than BSD or GNU is encumbered.
3. A file which contains downloadable binary data for use by the hardware is not encumbered, unless (1) or (2) apply to it. It must be stored in an architecture neutral ASCII format (file2c or uuencoding is recommended).
4. Any encumbered file requires specific approval from the Core Team before it is added to the repository.
5. Encumbered files go in src/contrib or src/sys/contrib.
6. The entire module should be kept together. There is no point in splitting it, unless there is code-sharing with non-encumbered code.
7. Object files are named arch/filename.o.uu>.
8. Kernel files:
    a. Should always be referenced in conf/files.* (for build simplicity).
    b. Should always be in LINT, but the Core Team decides per case if it should be commented out or not. The Core Team can, of course, change their minds later on.
    c. The Release Engineer decides whether or not it goes into the release.
9. User-land files:
    a. The Core team decides if the code should be part of make world.
    b. The Release Engineering decides if it goes into the release.

5.5. Shared Libraries

If you are adding shared library support to a port or other piece of software that does not have one, the version numbers should follow these rules. Generally, the resulting numbers will have nothing to do with the release version of the software.

The three principles of shared library building are:

- Start from 1.0
- If there is a change that is backwards compatible, bump minor number (note that ELF systems ignore the minor number)
- If there is an incompatible change, bump major number

For instance, added functions and bugfixes result in the minor version number being bumped, while deleted functions, changed function call syntax, etc. will force the major version number to change.

Stick to version numbers of the form major.minor (x.y). Our a.out dynamic linker does not handle version numbers of the form x.y.z well. Any version number after the y (i.e., the third digit) is totally ignored when comparing shared lib version numbers to decide which library to link with. Given two shared libraries that differ only in the "micro" revision, ld.so will link with the higher one. That is, if you link with libfoo.so.3.3.3, the linker only records 3.3 in the headers, and will link with anything starting with libfoo.so.3.(anything >= 3).(highest available).

ld.so will always use the highest "minor" revision. For instance, it will use libc.so.2.2 in preference to libc.so.2.0, even if the program was initially linked with libc.so.2.0.

In addition, our ELF dynamic linker does not handle minor version numbers at all. However, one should still specify a major and minor version number as our Makefile's "do the right thing" based on the type of system.

For non-port libraries, it is also our policy to change the shared library version number only once

between releases. In addition, it is our policy to change the major shared library version number only once between major OS releases (i.e., from 6.0 to 7.0). When you make a change to a system library that requires the version number to be bumped, check the Makefile's commit logs. It is the responsibility of the committer to ensure that the first such change since the release will result in the shared library version number in the Makefile to be updated, and any subsequent changes will not.

Chapter 6. Regression and Performance Testing

Regression tests are used to exercise a particular bit of the system to check that it works as expected, and to make sure that old bugs are not reintroduced.

The FreeBSD regression testing tools can be found in the FreeBSD source tree in the directory src/tools/regression.

6.1. Micro Benchmark Checklist

This section contains hints for doing proper micro-benchmarking on FreeBSD or of FreeBSD itself.

It is not possible to use all of the suggestions below every single time, but the more used, the better the benchmark' s ability to test small differences will be.

- Disable APM and any other kind of clock fiddling (ACPI ?).
- Run in single user mode. E.g., cron(8), and other daemons only add noise. The sshd(8) daemon can also cause problems. If ssh access is required during testing either disable the SSHv1 key regeneration, or kill the parent sshd daemon during the tests.
- Do not run ntpd(8).
- If syslog(3) events are generated, run syslogd(8) with an empty /etc/syslogd.conf, otherwise, do not run it.
- Minimize disk-I/O, avoid it entirely if possible.
- Do not mount file systems that are not needed.
- Mount /, /usr, and any other file system as read-only if possible. This removes atime updates to disk (etc.) from the I/O picture.
- Reinitialize the read/write test file system with newfs(8) and populate it from a tar(1) or dump(8) file before every run. Unmount and mount it before starting the test. This results in a consistent file system layout. For a worldstone test this would apply to /usr/obj (just reinitialize with newfs and mount). To get 100% reproducibility, populate the file system from a dd(1) file (i.e.: dd if=myimage of=/dev/ad0s1h bs=1m)
- Use malloc backed or preloaded md(4) partitions.
- Reboot between individual iterations of the test, this gives a more consistent state.
- Remove all non-essential device drivers from the kernel. For instance if USB is not needed for the test, do not put USB in the kernel. Drivers which attach often have timeouts ticking away.
- Unconfigure hardware that are not in use. Detach disks with atacontrol(8) and camcontrol(8) if the disks are not used for the test.
- Do not configure the network unless it is being tested, or wait until after the test has been performed to ship the results off to another computer.

  If the system must be connected to a public network, watch out for spikes of broadcast traffic. Even though it is hardly noticeable, it will take up CPU cycles. Multicast has similar caveats.
- Put each file system on its own disk. This minimizes jitter from head-seek optimizations.
- Minimize output to serial or VGA consoles. Running output into files gives less jitter. (Serial consoles easily become a bottleneck.) Do not touch keyboard while the test is running, even `space` or `back-space` shows up in the numbers.
- Make sure the test is long enough, but not too long. If the test is too short, timestamping is a problem. If it is too long temperature changes and drift will affect the frequency of the quartz crystals in the computer. Rule of thumb: more than a minute, less than an hour.
- Try to keep the temperature as stable as possible around the machine. This affects both quartz crystals and disk drive algorithms. To get real stable clock, consider stabilized clock injection.

E.g., get a OCXO + PLL, inject output into clock circuits instead of motherboard xtal. Contact Poul-Henning Kamp <phk@FreeBSD.org> for more information about this.

- Run the test at least 3 times but it is better to run more than 20 times both for "before" and "after" code. Try to interleave if possible (i.e.: do not run 20 times before then 20 times after), this makes it possible to spot environmental effects. Do not interleave 1:1, but 3:3, this makes it possible to spot interaction effects.

  A good pattern is: bababa{bbbaaa}*. This gives hint after the first 1+1 runs (so it is possible to stop the test if it goes entirely the wrong way), a standard deviation after the first 3+3 (gives a good indication if it is going to be worth a long run) and trending and interaction numbers later on.

- Use ministat(1) to see if the numbers are significant. Consider buying "Cartoon guide to statistics" ISBN: 0062731025, highly recommended, if you have forgotten or never learned about standard deviation and Student' s T.
- Do not use background fsck(8) unless the test is a benchmark of background fsck. Also, disable background_fsck in /etc/rc.conf unless the benchmark is not started at least 60+"fsck runtime" seconds after the boot, as rc(8) wakes up and checks if fsck needs to run on any file systems when background fsck is enabled. Likewise, make sure there are no snapshots lying around unless the benchmark is a test with snapshots.
- If the benchmark show unexpected bad performance, check for things like high interrupt volume from an unexpected source. Some versions of ACPI have been reported to "misbehave" and generate excess interrupts. To help diagnose odd test results, take a few snapshots of vmstat -i and look for anything unusual.
- Make sure to be careful about optimization parameters for kernel and userspace, likewise debugging. It is easy to let something slip through and realize later the test was not comparing the same thing.
- Do not ever benchmark with the WITNESS and INVARIANTS kernel options enabled unless the test is interested to benchmarking those features. WITNESS can cause 400%+ drops in performance. Likewise, userspace malloc(3) parameters default differently in -CURRENT from the way they ship in production releases.

6.2. The FreeBSD Source Tinderbox

The source Tinderbox consists of:

- A build script, tinderbox, that automates checking out a specific version of the FreeBSD source tree and building it.
- A supervisor script, tbmaster, that monitors individual Tinderbox instances, logs their output, and emails failure notices.
- A CGI script named index.cgi that reads a set of tbmaster logs and presents an easy-to-read HTML summary of them.
- A set of build servers that continually test the tip of the most important FreeBSD code branches.
- A webserver that keeps a complete set of Tinderbox logs and displays an up-to-date summary.

The scripts are maintained and were developed by Dag-Erling Smørgrav <des@FreeBSD.org>, and are now written in Perl, a move on from their original incarnation as shell scripts. All scripts and configuration files are kept in /projects/tinderbox/.

For more information about the tinderbox and tbmaster scripts at this stage, see their respective man pages: tinderbox(1) and tbmaster(1).

6.3. The index.cgi Script

The index.cgi script generates the HTML summary of tinderbox and tbmaster logs. Although originally intended to be used as a CGI script, as indicated by its name, this script can also be run from the command line or from a cron(8) job, in which case it will look for logs in the directory

where the script is located. It will automatically detect context, generating HTTP headers when it is run as a CGI script. It conforms to XHTML standards and is styled using CSS.

The script starts in the main() block by attempting to verify that it is running on the official Tinderbox website. If it is not, a page indicating it is not an official website is produced, and a URL to the official site is provided.

Next, it scans the log directory to get an inventory of configurations, branches and architectures for which log files exist, to avoid hard-coding a list into the script and potentially ending up with blank rows or columns. This information is derived from the names of the log files matching the following pattern:

```
tinderbox-$config-$branch-$arch-$machine.{brief,full}
```

The configurations used on the official Tinderbox build servers are named for the branches they build. For example, the releng_8 configuration is used to build RELENG_8 as well as all still-supported release branches.

Once all of this startup procedure has been successfully completed, do_config() is called for each configuration.

The do_config() function generates HTML for a single Tinderbox configuration.

It works by first generating a header row, then iterating over each branch build with the specified configuration, producing a single row of results for each in the following manner:

- For each item:
  - For each machine within that architecture:
    - If a brief log file exists, then:
      - Call success() to determine the outcome of the build.
      - Output the modification size.
      - Output the size of the brief log file with a link to the log file itself.
      - If a full log file also exists, then:
        - Output the size of the full log file with a link to the log file itself.
    - Otherwise:
      - No output.

The success() function mentioned above scans a brief log file for the string "tinderbox run completed" in order to determine whether the build was successful.

Configurations and branches are sorted according to their branch rank. This is computed as follows:

- HEAD and CURRENT have rank 9999.
- RELENG_x has rank xx99.
- RELENG_x_y has rank xxyy.

This means that HEAD always ranks highest, and RELENG branches are ranked in numerical order, with each STABLE branch ranking higher than the release branches forked off of it. For instance, for FreeBSD 8, the order from highest to lowest would be:

- RELENG_8 (branch rank 899).
- RELENG_8_3 (branch rank 803).
- RELENG_8_2 (branch rank 802).

- RELENG_8_1 (branch rank 801).
- RELENG_8_0 (branch rank 800).

The colors that Tinderbox uses for each cell in the table are defined by CSS. Successful builds are displayed with green text; unsuccessful builds are displayed with red text. The color fades as time passes since the corresponding build, with every half an hour bringing the color closer to grey.

6.4. Official Build Servers

The official Tinderbox build servers are hosted by Sentex Data Communications, who also host the FreeBSD Netperf Cluster.

Three build servers currently exist:

freebsd-current.sentex.ca builds:

- HEAD for amd64, arm, i386, i386/pc98, ia64, mips, powerpc, powerpc64, and sparc64.
- RELENG_9 and supported 9.X branches for amd64, arm, i386, i386/pc98, ia64, mips, powerpc, powerpc64, and sparc64.

freebsd-stable.sentex.ca builds:

- RELENG_8 and supported 8.X branches for amd64, i386, i386/pc98, ia64, mips, powerpc and sparc64.

freebsd-legacy.sentex.ca builds:

- RELENG_7 and supported 7.X branches for amd64, i386, i386/pc98, ia64, powerpc, and sparc64.

6.5. Official Summary Site

Summaries and logs from the official build servers are available online at http://tinderbox.FreeBSD.org, hosted by Dag-Erling Smørgrav <des@FreeBSD.org> and set up as follows:

- A cron(8) job checks the build servers at regular intervals and downloads any new log files using rsync(1).
- Apache is set up to use index.cgi as DirectoryIndex.

Part II: Interprocess Communication(IPC)

Chapter 7. Sockets

7.1. Synopsis

BSD sockets take interprocess communications to a new level. It is no longer necessary for the communicating processes to run on the same machine. They still can, but they do not have to.

Not only do these processes not have to run on the same machine, they do not have to run under the same operating system. Thanks to BSD sockets, your FreeBSD software can smoothly cooperate with a program running on a Macintosh®, another one running on a Sun™ workstation, yet another one running under Windows® 2000, all connected with an Ethernet-based local area network.

But your software can equally well cooperate with processes running in another building, or on another continent, inside a submarine, or a space shuttle.

It can also cooperate with processes that are not part of a computer (at least not in the strict sense of the word), but of such devices as printers, digital cameras, medical equipment. Just about anything capable of digital communications.

7.2. Networking and Diversity

We have already hinted on the diversity of networking. Many different systems have to talk to each other. And they have to speak the same language. They also have to understand the same language the same way.

People often think that body language is universal. But it is not. Back in my early teens, my father took me to Bulgaria. We were sitting at a table in a park in Sofia, when a vendor approached us trying to sell us some roasted almonds.

I had not learned much Bulgarian by then, so, instead of saying no, I shook my head from side to side, the "universal" body language for no. The vendor quickly started serving us some almonds.

I then remembered I had been told that in Bulgaria shaking your head sideways meant yes. Quickly, I started nodding my head up and down. The vendor noticed, took his almonds, and walked away. To an uninformed observer, I did not change the body language: I continued using the language of shaking and nodding my head. What changed was the meaning of the body language. At first, the vendor and I interpreted the same language as having completely different meaning. I had to adjust my own interpretation of that language so the vendor would understand.

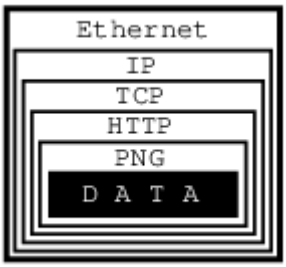
It is the same with computers: The same symbols may have different, even outright opposite meaning. Therefore, for two computers to understand each other, they must not only agree on the same language, but on the same interpretation of the language.

7.3. Protocols

While various programming languages tend to have complex syntax and use a number of multi-letter reserved words (which makes them easy for the human programmer to understand), the languages of data communications tend to be very terse. Instead of multi-byte words, they often use individual bits. There is a very convincing reason for it: While data travels inside your computer at speeds approaching the speed of light, it often travels considerably slower between two computers.

Because the languages used in data communications are so terse, we usually refer to them as protocols rather than languages.

As data travels from one computer to another, it always uses more than one protocol. These protocols are layered. The data can be compared to the inside of an onion: You have to peel off several layers of "skin" to get to the data. This is best illustrated with a picture:



In this example, we are trying to get an image from a web page we are connected to via an Ethernet.

The image consists of raw data, which is simply a sequence of RGB values that our software can process, i.e., convert into an image and display on our monitor.

Alas, our software has no way of knowing how the raw data is organized: Is it a sequence of RGB values, or a sequence of grayscale intensities, or perhaps of CMYK encoded colors? Is the data represented by 8-bit quanta, or are they 16 bits in size, or perhaps 4 bits? How many rows and columns does the image consist of? Should certain pixels be transparent?

I think you get the picture…

To inform our software how to handle the raw data, it is encoded as a PNG file. It could be a GIF, or a JPEG, but it is a PNG.

And PNG is a protocol.

At this point, I can hear some of you yelling, "No, it is not! It is a file format!"

Well, of course it is a file format. But from the perspective of data communications, a file format is a protocol: The file structure is a language, a terse one at that, communicating to our process how the data is organized. Ergo, it is a protocol.

Alas, if all we received was the PNG file, our software would be facing a serious problem: How is it supposed to know the data is representing an image, as opposed to some text, or perhaps a sound, or what not? Secondly, how is it supposed to know the image is in the PNG format as opposed to GIF, or JPEG, or some other image format?

To obtain that information, we are using another protocol: HTTP. This protocol can tell us exactly that the data represents an image, and that it uses the PNG protocol. It can also tell us some other things, but let us stay focused on protocol layers here.

So, now we have some data wrapped in the PNG protocol, wrapped in the HTTP protocol. How did we get it from the server?

By using TCP/IP over Ethernet, that is how. Indeed, that is three more protocols. Instead of continuing inside out, I am now going to talk about Ethernet, simply because it is easier to explain the rest that way.

Ethernet is an interesting system of connecting computers in a local area network (LAN). Each computer has a network interface card (NIC), which has a unique 48-bit ID called its address. No two Ethernet NICs in the world have the same address.

These NICs are all connected with each other. Whenever one computer wants to communicate with another in the same Ethernet LAN, it sends a message over the network. Every NIC sees the message. But as part of the Ethernet protocol, the data contains the address of the destination NIC (among other things). So, only one of all the network interface cards will pay attention to it, the rest will ignore it.

But not all computers are connected to the same network. Just because we have received the data over our Ethernet does not mean it originated in our own local area network. It could have come to us from some other network (which may not even be Ethernet based) connected with our own

network via the Internet.

All data is transferred over the Internet using IP, which stands for Internet Protocol. Its basic role is to let us know where in the world the data has arrived from, and where it is supposed to go to. It does not guarantee we will receive the data, only that we will know where it came from if we do receive it.

Even if we do receive the data, IP does not guarantee we will receive various chunks of data in the same order the other computer has sent it to us. So, we can receive the center of our image before we receive the upper left corner and after the lower right, for example.

It is TCP (Transmission Control Protocol) that asks the sender to resend any lost data and that places it all into the proper order.

All in all, it took five different protocols for one computer to communicate to another what an image looks like. We received the data wrapped into the PNG protocol, which was wrapped into the HTTP protocol, which was wrapped into the TCP protocol, which was wrapped into the IP protocol, which was wrapped into the Ethernet protocol.

Oh, and by the way, there probably were several other protocols involved somewhere on the way. For example, if our LAN was connected to the Internet through a dial-up call, it used the PPP protocol over the modem which used one (or several) of the various modem protocols, et cetera, et cetera, et cetera…

As a developer you should be asking by now, "How am I supposed to handle it all?"

Luckily for you, you are not supposed to handle it all. You are supposed to handle some of it, but not all of it. Specifically, you need not worry about the physical connection (in our case Ethernet and possibly PPP, etc). Nor do you need to handle the Internet Protocol, or the Transmission Control Protocol.

In other words, you do not have to do anything to receive the data from the other computer. Well, you do have to ask for it, but that is almost as simple as opening a file.

Once you have received the data, it is up to you to figure out what to do with it. In our case, you would need to understand the HTTP protocol and the PNG file structure.

To use an analogy, all the internetworking protocols become a gray area: Not so much because we do not understand how it works, but because we are no longer concerned about it. The sockets interface takes care of this gray area for us:

We only need to understand any protocols that tell us how to interpret the data, not how to receive it from another process, nor how to send it to another process.

7.4. The Sockets Model

BSD sockets are built on the basic UNIX® model: Everything is a file. In our example, then, sockets would let us receive an HTTP file, so to speak. It would then be up to us to extract the PNG file from it.

Because of the complexity of internetworking, we cannot just use the open system call, or the

open() C function. Instead, we need to take several steps to "opening" a socket.

Once we do, however, we can start treating the socket the same way we treat any file descriptor: We can read from it, write to it, pipe it, and, eventually, close it.

7.5. Essential Socket Functions

While FreeBSD offers different functions to work with sockets, we only need four to "open" a socket. And in some cases we only need two.

7.5.1. The Client-Server Difference

Typically, one of the ends of a socket-based data communication is a server, the other is a client.

7.5.1.1. The Common Elements

7.5.1.1.1. socket

The one function used by both, clients and servers, is socket(2). It is declared this way:

```
int socket(int domain, int type, int protocol);
```

The return value is of the same type as that of open, an integer. FreeBSD allocates its value from the same pool as that of file handles. That is what allows sockets to be treated the same way as files.

The domain argument tells the system what protocol family you want it to use. Many of them exist, some are vendor specific, others are very common. They are declared in sys/socket.h.

Use PF_INET for UDP, TCP and other Internet protocols (IPv4).

Five values are defined for the type argument, again, in sys/socket.h. All of them start with “SOCK_”. The most common one is SOCK_STREAM, which tells the system you are asking for a reliable stream delivery service (which is TCP when used with PF_INET).

If you asked for SOCK_DGRAM, you would be requesting a connectionless datagram delivery service (in our case, UDP).

If you wanted to be in charge of the low-level protocols (such as IP), or even network interfaces (e.g., the Ethernet), you would need to specify SOCK_RAW.

Finally, the protocol argument depends on the previous two arguments, and is not always meaningful. In that case, use 0 for its value.

The Unconnected Socket

Nowhere, in the socket function have we specified to what other system we should be connected. Our newly created socket remains unconnected.

This is on purpose: To use a telephone analogy, we have just attached a modem to the phone line. We have neither told the modem to make a call, nor to answer if the phone rings.

7.5.1.1.2. sockaddr

Various functions of the sockets family expect the address of (or pointer to, to use C terminology) a small area of the memory. The various C declarations in the sys/socket.h refer to it as struct sockaddr. This structure is declared in the same file:

```
/*
 * Structure used by kernel to store most
 * addresses.
 */
struct sockaddr {
   unsigned char   sa_len;    /* total length */
   sa_family_t sa_family;  /* address family */
   char      sa_data[14];   /* actually longer; address value */
};
#define SOCK_MAXADDRLEN 255    /* longest possible addresses */
```

Please note the vagueness with which the sa_data field is declared, just as an array of 14 bytes, with the comment hinting there can be more than 14 of them.

This vagueness is quite deliberate. Sockets is a very powerful interface. While most people perhaps think of it as nothing more than the Internet interface-and most applications probably use it for that nowadays-sockets can be used for just about any kind of interprocess communications, of which the Internet (or, more precisely, IP) is only one.

The sys/socket.h refers to the various types of protocols sockets will handle as address families, and lists them right before the definition of sockaddr:

```
/*
 * Address families.
 */
#define AF_UNSPEC   0      /* unspecified */
#define AF_LOCAL    1      /* local to host (pipes, portals) */
#define AF_UNIX     AF_LOCAL   /* backward compatibility */
#define AF_INET     2      /* internetwork: UDP, TCP, etc. */
#define AF_IMPLINK  3      /* arpanet imp addresses */
#define AF_PUP      4      /* pup protocols: e.g. BSP */
#define AF_CHAOS    5      /* mit CHAOS protocols */
#define AF_NS       6      /* XEROX NS protocols */
#define AF_ISO      7      /* ISO protocols */
#define AF_OSI      AF_ISO
#define AF_ECMA     8      /* European computer manufacturers */
#define AF_DATAKIT  9      /* datakit protocols */
#define AF_CCITT    10     /* CCITT protocols, X.25 etc */
#define AF_SNA      11     /* IBM SNA */
#define AF_DECnet   12     /* DECnet */
#define AF_DLI      13     /* DEC Direct data link interface */
#define AF_LAT      14     /* LAT */
#define AF_HYLINK   15     /* NSC Hyperchannel */
#define AF_APPLETALK    16     /* Apple Talk */
#define AF_ROUTE    17     /* Internal Routing Protocol */
```

```
#define AF_LINK    18    /* Link layer interface */
#define pseudo_AF_XTP  19    /* eXpress Transfer Protocol (no AF) */
#define AF_COIP    20    /* connection-oriented IP, aka ST II */
#define AF_CNT     21    /* Computer Network Technology */
#define pseudo_AF_RTIP 22    /* Help Identify RTIP packets */
#define AF_IPX     23    /* Novell Internet Protocol */
#define AF_SIP     24    /* Simple Internet Protocol */
#define pseudo_AF_PIP  25    /* Help Identify PIP packets */
#define AF_ISDN    26    /* Integrated Services Digital Network*/
#define AF_E164    AF_ISDN    /* CCITT E.164 recommendation */
#define pseudo_AF_KEY  27    /* Internal key-management function */
#define AF_INET6   28    /* IPv6 */
#define AF_NATM    29    /* native ATM access */
#define AF_ATM     30    /* ATM */
#define pseudo_AF_HDRCMPLT 31     /* Used by BPF to not rewrite headers
                * in interface output routine
                */
#define AF_NETGRAPH 32    /* Netgraph sockets */
#define AF_SLOW    33    /* 802.3ad slow protocol */
#define AF_SCLUSTER 34    /* Sitara cluster protocol */
#define AF_ARP     35
#define AF_BLUETOOTH   36    /* Bluetooth sockets */
#define AF_MAX     37
```

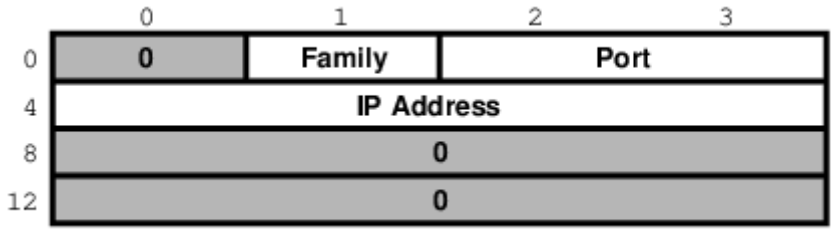
The one used for IP is AF_INET. It is a symbol for the constant 2.

It is the address family listed in the sa_family field of sockaddr that decides how exactly the vaguely named bytes of sa_data will be used.

Specifically, whenever the address family is AF_INET, we can use struct sockaddr_in found in netinet/in.h, wherever sockaddr is expected:

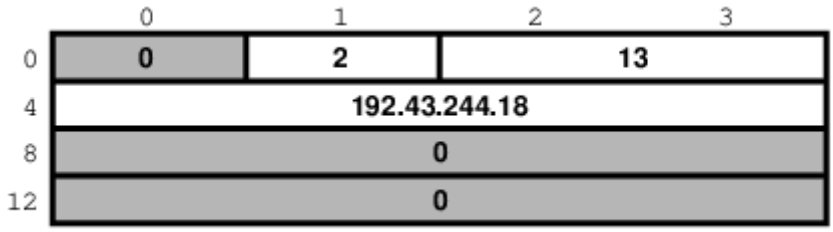
```
/*
 * Socket address, internet style.
 */
struct sockaddr_in {
   uint8_t    sin_len;
   sa_family_t sin_family;
   in_port_t  sin_port;
   struct  in_addr sin_addr;
   char    sin_zero[8];
};
```

We can visualize its organization this way:



The three important fields are sin_family, which is byte 1 of the structure, sin_port, a 16-bit value found in bytes 2 and 3, and sin_addr, a 32-bit integer representation of the IP address, stored in bytes 4-7.

Now, let us try to fill it out. Let us assume we are trying to write a client for the daytime protocol, which simply states that its server will write a text string representing the current date and time to port 13. We want to use TCP/IP, so we need to specify AF_INET in the address family field. AF_INET is defined as 2. Let us use the IP address of 192.43.244.18, which is the time server of US federal government (time.nist.gov).



By the way the sin_addr field is declared as being of the struct in_addr type, which is defined in netinet/in.h:

```
/*
 * Internet address (a structure for historical reasons)
 */
struct in_addr {
   in_addr_t s_addr;
};
```

In addition, in_addr_t is a 32-bit integer.

The 192.43.244.18 is just a convenient notation of expressing a 32-bit integer by listing all of its 8-bit bytes, starting with the most significant one.

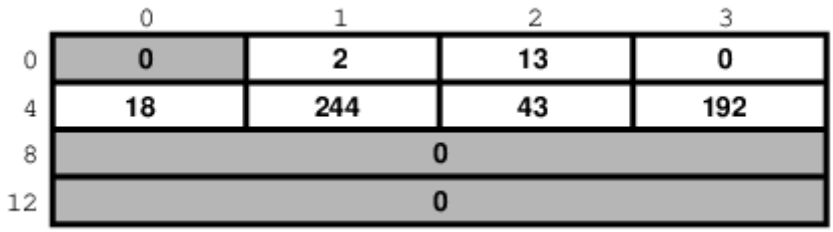
So far, we have viewed sockaddr as an abstraction. Our computer does not store short integers as a single 16-bit entity, but as a sequence of 2 bytes. Similarly, it stores 32-bit integers as a sequence of 4 bytes.

Suppose we coded something like this:

```
sa.sin_family     = AF_INET;
sa.sin_port       = 13;
sa.sin_addr.s_addr = (((((192 << 8) | 43) << 8) | 244) << 8) | 18;
```

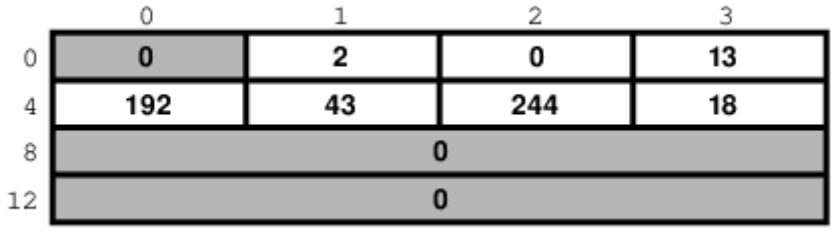
What would the result look like?

Well, that depends, of course. On a Pentium®, or other x86, based computer, it would look like this:



	0	1	2	3
0	0	2	13	0
4	18	244	43	192
8	0			
12	0			

On a different system, it might look like this:



	0	1	2	3
0	0	2	0	13
4	192	43	244	18
8	0			
12	0			

And on a PDP it might look different yet. But the above two are the most common ways in use today.

Ordinarily, wanting to write portable code, programmers pretend that these differences do not exist. And they get away with it (except when they code in assembly language). Alas, you cannot get away with it that easily when coding for sockets.

Why?

Because when communicating with another computer, you usually do not know whether it stores data most significant byte (MSB) or least significant byte (LSB) first.

You might be wondering, "So, will sockets not handle it for me?"

It will not.

While that answer may surprise you at first, remember that the general sockets interface only understands the sa_len and sa_family fields of the sockaddr structure. You do not have to worry about the byte order there (of course, on FreeBSD sa_family is only 1 byte anyway, but many other UNIX® systems do not have sa_len and use 2 bytes for sa_family, and expect the data in whatever order is native to the computer).

But the rest of the data is just sa_data[14] as far as sockets goes. Depending on the address family, sockets just forwards that data to its destination.

Indeed, when we enter a port number, it is because we want the other computer to know what service we are asking for. And, when we are the server, we read the port number so we know what service the other computer is expecting from us. Either way, sockets only has to forward the port number as data. It does not interpret it in any way.

Similarly, we enter the IP address to tell everyone on the way where to send our data to. Sockets, again, only forwards it as data.

That is why, we (the programmers, not the sockets) have to distinguish between the byte order used by our computer and a conventional byte order to send the data in to the other computer.

We will call the byte order our computer uses the host byte order, or just the host order.

There is a convention of sending the multi-byte data over IP MSB first. This, we will refer to as the network byte order, or simply the network order.

Now, if we compiled the above code for an Intel based computer, our host byte order would produce:

	0	1	2	3
0	0	2	13	0
4	18	244	43	192
8	0			
12	0			

But the network byte order requires that we store the data MSB first:

	0	1	2	3
0	0	2	0	13
4	192	43	244	18
8	0			
12	0			

Unfortunately, our host order is the exact opposite of the network order.

We have several ways of dealing with it. One would be to reverse the values in our code:

```
sa.sin_family     = AF_INET;
sa.sin_port       = 13 << 8;
sa.sin_addr.s_addr = (((((18 << 8) | 244) << 8) | 43) << 8) | 192;
```

This will trick our compiler into storing the data in the network byte order. In some cases, this is exactly the way to do it (e.g., when programming in assembly language). In most cases, however, it can cause a problem.

Suppose, you wrote a sockets-based program in C. You know it is going to run on a Pentium®, so you enter all your constants in reverse and force them to the network byte order. It works well.

Then, some day, your trusted old Pentium® becomes a rusty old Pentium®. You replace it with a system whose host order is the same as the network order. You need to recompile all your software. All of your software continues to perform well, except the one program you wrote.

You have since forgotten that you had forced all of your constants to the opposite of the host order. You spend some quality time tearing out your hair, calling the names of all gods you ever heard of (and some you made up), hitting your monitor with a nerf bat, and performing all the other traditional ceremonies of trying to figure out why something that has worked so well is suddenly not working at all.

Eventually, you figure it out, say a couple of swear words, and start rewriting your code.

Luckily, you are not the first one to face the problem. Someone else has created the htons(3) and htonl(3) C functions to convert a short and long respectively from the host byte order to the network byte order, and the ntohs(3) and ntohl(3) C functions to go the other way.

On MSB-first systems these functions do nothing. On LSB-first systems they convert values to the proper order.

So, regardless of what system your software is compiled on, your data will end up in the correct order if you use these functions.

7.5.1.2. Client Functions

Typically, the client initiates the connection to the server. The client knows which server it is about to call: It knows its IP address, and it knows the port the server resides at. It is akin to you picking up the phone and dialing the number (the address), then, after someone answers, asking for the person in charge of wingdings (the port).

7.5.1.2.1. connect

Once a client has created a socket, it needs to connect it to a specific port on a remote system. It uses connect(2):

```
int connect(int s, const struct sockaddr *name, socklen_t namelen);
```

The s argument is the socket, i.e., the value returned by the socket function. The name is a pointer to sockaddr, the structure we have talked about extensively. Finally, namelen informs the system how many bytes are in our sockaddr structure.

If connect is successful, it returns 0. Otherwise it returns -1 and stores the error code in errno.

There are many reasons why connect may fail. For example, with an attempt to an Internet connection, the IP address may not exist, or it may be down, or just too busy, or it may not have a server listening at the specified port. Or it may outright refuse any request for specific code.

7.5.1.2.2. Our First Client

We now know enough to write a very simple client, one that will get current time from 192.43.244.18 and print it to stdout.

```
/*
 * daytime.c
 *
 * Programmed by G. Adam Stanislav
 */
#include <stdio.h>
#include <string.h>
#include <sys/types.h>
#include <sys/socket.h>
#include <netinet/in.h>

int main() {
 register int s;
 register int bytes;
 struct sockaddr_in sa;
 char buffer[BUFSIZ+1];

 if ((s = socket(PF_INET, SOCK_STREAM, 0)) < 0) {
  perror("socket");
  return 1;
 }
```

```
  bzero(&sa, sizeof sa);

  sa.sin_family = AF_INET;
  sa.sin_port = htons(13);
  sa.sin_addr.s_addr = htonl((((((192 << 8) | 43) << 8) | 244) << 8) | 18);
  if (connect(s, (struct sockaddr *)&sa, sizeof sa) < 0) {
   perror("connect");
   close(s);
   return 2;
  }

  while ((bytes = read(s, buffer, BUFSIZ)) > 0)
   write(1, buffer, bytes);

  close(s);
  return 0;
}
```

Go ahead, enter it in your editor, save it as daytime.c, then compile and run it:

```
% cc -O3 -o daytime daytime.c
% ./daytime

52079 01-06-19 02:29:25 50 0 1 543.9 UTC(NIST) *
%
```

In this case, the date was June 19, 2001, the time was 02:29:25 UTC. Naturally, your results will vary.

7.5.1.3. Server Functions

The typical server does not initiate the connection. Instead, it waits for a client to call it and request services. It does not know when the client will call, nor how many clients will call. It may be just sitting there, waiting patiently, one moment, The next moment, it can find itself swamped with requests from a number of clients, all calling in at the same time.

The sockets interface offers three basic functions to handle this.

7.5.1.3.1. bind

Ports are like extensions to a phone line: After you dial a number, you dial the extension to get to a specific person or department.

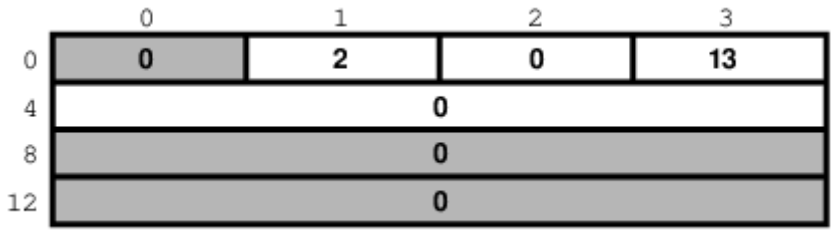
There are 65535 IP ports, but a server usually processes requests that come in on only one of them. It is like telling the phone room operator that we are now at work and available to answer the phone at a specific extension. We use bind(2) to tell sockets which port we want to serve.

```
int bind(int s, const struct sockaddr *addr, socklen_t addrlen);
```

Beside specifying the port in addr, the server may include its IP address. However, it can just use the symbolic constant INADDR_ANY to indicate it will serve all requests to the specified port regardless of what its IP address is. This symbol, along with several similar ones, is declared in netinet/in.h

```
#define INADDR_ANY     (u_int32_t)0x00000000
```

Suppose we were writing a server for the daytime protocol over TCP/IP. Recall that it uses port 13. Our sockaddr_in structure would look like this:



7.5.1.3.2. listen

To continue our office phone analogy, after you have told the phone central operator what extension you will be at, you now walk into your office, and make sure your own phone is plugged in and the ringer is turned on. Plus, you make sure your call waiting is activated, so you can hear the phone ring even while you are talking to someone.

The server ensures all of that with the listen(2) function.

```
int listen(int s, int backlog);
```

In here, the backlog variable tells sockets how many incoming requests to accept while you are busy processing the last request. In other words, it determines the maximum size of the queue of pending connections.

7.5.1.3.3. accept

After you hear the phone ringing, you accept the call by answering the call. You have now established a connection with your client. This connection remains active until either you or your client hang up.

The server accepts the connection by using the accept(2) function.

```
int accept(int s, struct sockaddr *addr, socklen_t *addrlen);
```

Note that this time addrlen is a pointer. This is necessary because in this case it is the socket that fills out addr, the sockaddr_in structure.

The return value is an integer. Indeed, the accept returns a new socket. You will use this new socket to communicate with the client.

What happens to the old socket? It continues to listen for more requests (remember the backlog variable we passed to listen?) until we close it.

Now, the new socket is meant only for communications. It is fully connected. We cannot pass it to listen again, trying to accept additional connections.

7.5.1.3.4. Our First Server

Our first server will be somewhat more complex than our first client was: Not only do we have more sockets functions to use, but we need to write it as a daemon.

This is best achieved by creating a child process after binding the port. The main process then exits and returns control to the shell (or whatever program invoked it).

The child calls listen, then starts an endless loop, which accepts a connection, serves it, and eventually closes its socket.

```
/*
 * daytimed - a port 13 server
 *
 * Programmed by G. Adam Stanislav
 * June 19, 2001
 */
#include <stdio.h>
#include <string.h>
#include <time.h>
#include <unistd.h>
#include <sys/types.h>
#include <sys/socket.h>
#include <netinet/in.h>

#define BACKLOG 4

int main() {
   register int s, c;
   int b;
   struct sockaddr_in sa;
   time_t t;
   struct tm *tm;
   FILE *client;

   if ((s = socket(PF_INET, SOCK_STREAM, 0)) < 0) {
      perror("socket");
      return 1;
   }

   bzero(&sa, sizeof sa);

   sa.sin_family = AF_INET;
   sa.sin_port   = htons(13);

   if (INADDR_ANY)
```

```
    sa.sin_addr.s_addr = htonl(INADDR_ANY);

  if (bind(s, (struct sockaddr *)&sa, sizeof sa) < 0) {
    perror("bind");
    return 2;
  }

  switch (fork()) {
    case -1:
      perror("fork");
      return 3;
      break;
    default:
      close(s);
      return 0;
      break;
    case 0:
      break;
  }

  listen(s, BACKLOG);

  for (;;) {
    b = sizeof sa;

    if ((c = accept(s, (struct sockaddr *)&sa, &b)) < 0) {
      perror("daytimed accept");
      return 4;
    }

    if ((client = fdopen(c, "w")) == NULL) {
      perror("daytimed fdopen");
      return 5;
    }

    if ((t = time(NULL)) < 0) {
      perror("daytimed time");

      return 6;
    }

    tm = gmtime(&t);
```

```
      fprintf(client, "%.4i-%.2i-%.2iT%.2i:%.2i:%.2iZ\n",
        tm->tm_year + 1900,
        tm->tm_mon + 1,
        tm->tm_mday,
        tm->tm_hour,
        tm->tm_min,
        tm->tm_sec);

      fclose(client);
    }
}
```

We start by creating a socket. Then we fill out the sockaddr_in structure in sa. Note the conditional use of INADDR_ANY:

```
if (INADDR_ANY)
    sa.sin_addr.s_addr = htonl(INADDR_ANY);
```

Its value is 0. Since we have just used bzero on the entire structure, it would be redundant to set it to 0 again. But if we port our code to some other system where INADDR_ANY is perhaps not a zero, we need to assign it to sa.sin_addr.s_addr. Most modern C compilers are clever enough to notice that INADDR_ANY is a constant. As long as it is a zero, they will optimize the entire conditional statement out of the code.

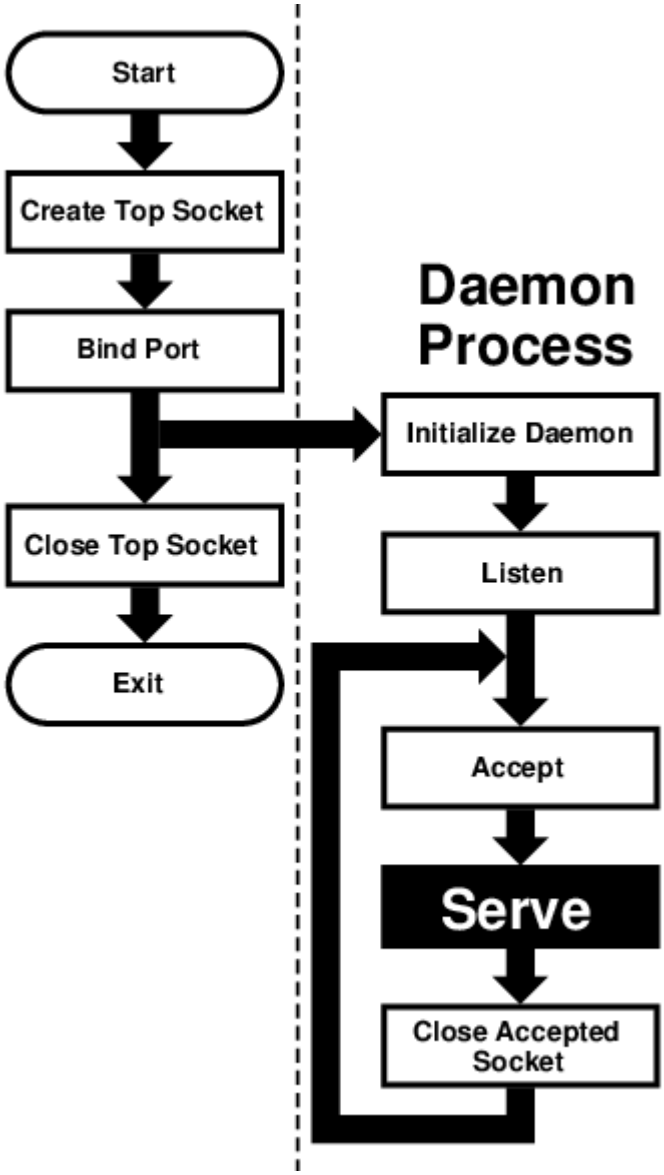
After we have called bind successfully, we are ready to become a daemon: We use fork to create a child process. In both, the parent and the child, the s variable is our socket. The parent process will not need it, so it calls close, then it returns 0 to inform its own parent it had terminated successfully.

Meanwhile, the child process continues working in the background. It calls listen and sets its backlog to 4. It does not need a large value here because daytime is not a protocol many clients request all the time, and because it can process each request instantly anyway.

Finally, the daemon starts an endless loop, which performs the following steps:

1. Call accept. It waits here until a client contacts it. At that point, it receives a new socket, c, which it can use to communicate with this particular client.
2. It uses the C function fdopen to turn the socket from a low-level file descriptor to a C-style FILE pointer. This will allow the use of fprintf later on.
3. It checks the time, and prints it in the ISO 8601 format to the client "file". It then uses fclose to close the file. That will automatically close the socket as well.

We can generalize this, and use it as a model for many other servers:



This flowchart is good for sequential servers, i.e., servers that can serve one client at a time, just as we were able to with our daytime server. This is only possible whenever there is no real "conversation" going on between the client and the server: As soon as the server detects a connection to the client, it sends out some data and closes the connection. The entire operation may take nanoseconds, and it is finished.

The advantage of this flowchart is that, except for the brief moment after the parent forks and before it exits, there is always only one process active: Our server does not take up much memory and other system resources.

Note that we have added initialize daemon in our flowchart. We did not need to initialize our own daemon, but this is a good place in the flow of the program to set up any signal handlers, open any files we may need, etc.

Just about everything in the flow chart can be used literally on many different servers. The serve entry is the exception. We think of it as a "black box", i.e., something you design specifically for your own server, and just "plug it into the rest."

Not all protocols are that simple. Many receive a request from the client, reply to it, then receive another request from the same client. Because of that, they do not know in advance how long they will be serving the client. Such servers usually start a new process for each client. While the new process is serving its client, the daemon can continue listening for more connections.

Now, go ahead, save the above source code as daytimed.c (it is customary to end the names of daemons with the letter d). After you have compiled it, try running it:

```
% ./daytimed
bind: Permission denied
%
```

What happened here? As you will recall, the daytime protocol uses port 13. But all ports below 1024 are reserved to the superuser (otherwise, anyone could start a daemon pretending to serve a commonly used port, while causing a security breach).

Try again, this time as the superuser:

```
# ./daytimed
#
```

What… Nothing? Let us try again:

```
# ./daytimed


bind: Address already in use
#
```

Every port can only be bound by one program at a time. Our first attempt was indeed successful: It started the child daemon and returned quietly. It is still running and will continue to run until you either kill it, or any of its system calls fail, or you reboot the system.

Fine, we know it is running in the background. But is it working? How do we know it is a proper daytime server? Simple:

```
% telnet localhost 13


Trying ::1...
telnet: connect to address ::1: Connection refused
Trying 127.0.0.1...
Connected to localhost.
Escape character is '^]'.
2001-06-19T21:04:42Z
Connection closed by foreign host.
%
```

telnet tried the new IPv6, and failed. It retried with IPv4 and succeeded. The daemon works.

If you have access to another UNIX® system via telnet, you can use it to test accessing the server remotely. My computer does not have a static IP address, so this is what I did:

```
% who


whizkid      ttyp0   Jun 19 16:59   (216.127.220.143)
```

```
xxx          ttyp1   Jun 19 16:06   (xx.xx.xx.xx)
% telnet 216.127.220.143 13

Trying 216.127.220.143...
Connected to r47.bfm.org.
Escape character is '^]'.
2001-06-19T21:31:11Z
Connection closed by foreign host.
%
```

Again, it worked. Will it work using the domain name?

```
% telnet r47.bfm.org 13

Trying 216.127.220.143...
Connected to r47.bfm.org.
Escape character is '^]'.
2001-06-19T21:31:40Z
Connection closed by foreign host.
%
```

By the way, telnet prints the Connection closed by foreign host message after our daemon has closed the socket. This shows us that, indeed, using fclose(client); in our code works as advertised.

7.6. Helper Functions

FreeBSD C library contains many helper functions for sockets programming. For example, in our sample client we hard coded the time.nist.gov IP address. But we do not always know the IP address. Even if we do, our software is more flexible if it allows the user to enter the IP address, or even the domain name.

7.6.1. gethostbyname

While there is no way to pass the domain name directly to any of the sockets functions, the FreeBSD C library comes with the gethostbyname(3) and gethostbyname2(3) functions, declared in netdb.h.

```
struct hostent * gethostbyname(const char *name);
struct hostent * gethostbyname2(const char *name, int af);
```

Both return a pointer to the hostent structure, with much information about the domain. For our purposes, the h_addr_list[0] field of the structure points at h_length bytes of the correct address, already stored in the network byte order.

This allows us to create a much more flexible-and much more useful-version of our daytime program:

```
/*
 * daytime.c
```

```
 *
 * Programmed by G. Adam Stanislav
 * 19 June 2001
 */
#include <stdio.h>
#include <string.h>
#include <sys/types.h>
#include <sys/socket.h>
#include <netinet/in.h>
#include <netdb.h>

int main(int argc, char *argv[]) {
 register int s;
 register int bytes;
 struct sockaddr_in sa;
 struct hostent *he;
 char buf[BUFSIZ+1];
 char *host;

 if ((s = socket(PF_INET, SOCK_STREAM, 0)) < 0) {
  perror("socket");
  return 1;
 }

 bzero(&sa, sizeof sa);

 sa.sin_family = AF_INET;
 sa.sin_port = htons(13);

 host = (argc > 1) ? (char *)argv[1] : "time.nist.gov";

 if ((he = gethostbyname(host)) == NULL) {
  herror(host);
  return 2;
 }

 bcopy(he->h_addr_list[0],&sa.sin_addr, he->h_length);

 if (connect(s, (struct sockaddr *)&sa, sizeof sa) < 0) {
  perror("connect");
  return 3;
 }
```

```
  while ((bytes = read(s, buf, BUFSIZ)) > 0)
    write(1, buf, bytes);

  close(s);
  return 0;
}
```

We now can type a domain name (or an IP address, it works both ways) on the command line, and the program will try to connect to its daytime server. Otherwise, it will still default to time.nist.gov. However, even in this case we will use gethostbyname rather than hard coding 192.43.244.18. That way, even if its IP address changes in the future, we will still find it.

Since it takes virtually no time to get the time from your local server, you could run daytime twice in a row: First to get the time from time.nist.gov, the second time from your own system. You can then compare the results and see how exact your system clock is:

```
% daytime ; daytime localhost

52080 01-06-20 04:02:33 50 0 0 390.2 UTC(NIST) *
2001-06-20T04:02:35Z
%
```

As you can see, my system was two seconds ahead of the NIST time.

7.6.2. getservbyname

Sometimes you may not be sure what port a certain service uses. The getservbyname(3) function, also declared in netdb.h comes in very handy in those cases:

```
struct servent * getservbyname(const char *name, const char *proto);
```

The servent structure contains the s_port, which contains the proper port, already in network byte order.

Had we not known the correct port for the daytime service, we could have found it this way:

```
struct servent *se;
  ...
  if ((se = getservbyname("daytime", "tcp")) == NULL {
    fprintf(stderr, "Cannot determine which port to use.\n");
    return 7;
  }
  sa.sin_port = se->s_port;
```

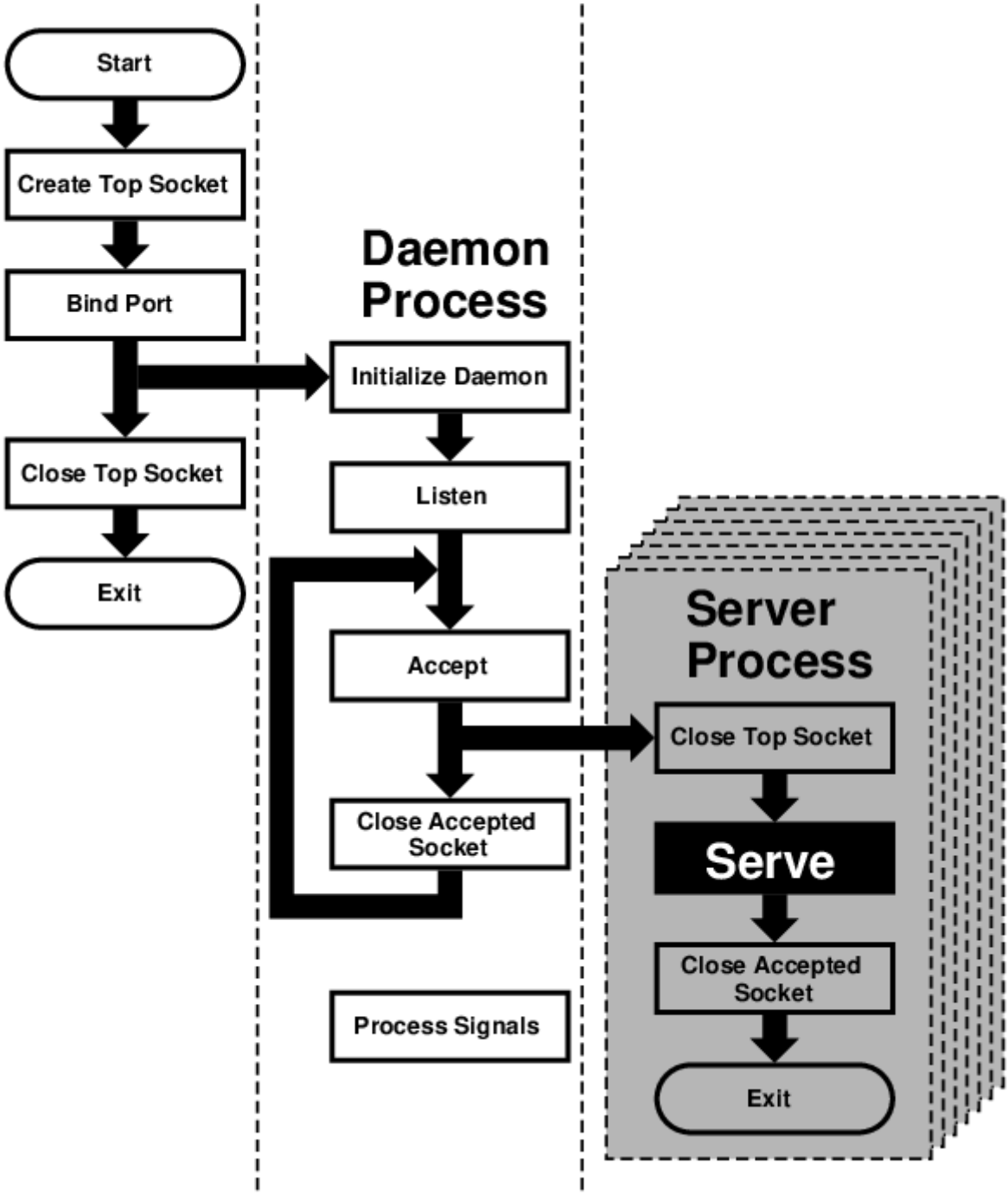
You usually do know the port. But if you are developing a new protocol, you may be testing it on an unofficial port. Some day, you will register the protocol and its port (if nowhere else, at least in your /etc/services, which is where getservbyname looks). Instead of returning an error in the above

code, you just use the temporary port number. Once you have listed the protocol in /etc/services, your software will find its port without you having to rewrite the code.

7.7. Concurrent Servers

Unlike a sequential server, a concurrent server has to be able to serve more than one client at a time. For example, a chat server may be serving a specific client for hours-it cannot wait till it stops serving a client before it serves the next one.

This requires a significant change in our flowchart:



We moved the serve from the daemon process to its own server process. However, because each child process inherits all open files (and a socket is treated just like a file), the new process inherits not only the "accepted handle," i.e., the socket returned by the accept call, but also the top socket, i.e., the one opened by the top process right at the beginning.

However, the server process does not need this socket and should close it immediately. Similarly, the daemon process no longer needs the accepted socket, and not only should, but must close it-

otherwise, it will run out of available file descriptors sooner or later.

After the server process is done serving, it should close the accepted socket. Instead of returning to accept, it now exits.

Under UNIX®, a process does not really exit. Instead, it returns to its parent. Typically, a parent process waits for its child process, and obtains a return value. However, our daemon process cannot simply stop and wait. That would defeat the whole purpose of creating additional processes. But if it never does wait, its children will become zombies-no longer functional but still roaming around.

For that reason, the daemon process needs to set signal handlers in its initialize daemon phase. At least a SIGCHLD signal has to be processed, so the daemon can remove the zombie return values from the system and release the system resources they are taking up.

That is why our flowchart now contains a process signals box, which is not connected to any other box. By the way, many servers also process SIGHUP, and typically interpret as the signal from the superuser that they should reread their configuration files. This allows us to change settings without having to kill and restart these servers.

Chapter 8. IPv6 Internals

8.1. IPv6/IPsec Implementation

This section should explain IPv6 and IPsec related implementation internals. These functionalities are derived from KAME project

8.1.1. IPv6

8.1.1.1. Conformance

The IPv6 related functions conforms, or tries to conform to the latest set of IPv6 specifications. For future reference we list some of the relevant documents below (NOTE: this is not a complete list - this is too hard to maintain…).

For details please refer to specific chapter in the document, RFCs, manual pages, or comments in the source code.

Conformance tests have been performed on the KAME STABLE kit at TAHI project. Results can be viewed at http://www.tahi.org/report/KAME/. We also attended University of New Hampshire IOL tests (http://www.iol.unh.edu/) in the past, with our past snapshots.

- RFC1639: FTP Operation Over Big Address Records (FOOBAR)
  - RFC2428 is preferred over RFC1639. FTP clients will first try RFC2428, then RFC1639 if failed.
- RFC1886: DNS Extensions to support IPv6
- RFC1933: Transition Mechanisms for IPv6 Hosts and Routers
  - IPv4 compatible address is not supported.
  - automatic tunneling (described in 4.3 of this RFC) is not supported.
  - gif(4) interface implements IPv[46]-over-IPv[46] tunnel in a generic way, and it covers "configured tunnel" described in the spec. See 23.5.1.5 in this document for details.
- RFC1981: Path MTU Discovery for IPv6
- RFC2080: RIPng for IPv6
  - usr.sbin/route6d support this.
- RFC2292: Advanced Sockets API for IPv6
  - For supported library functions/kernel APIs, see sys/netinet6/ADVAPI.
- RFC2362: Protocol Independent Multicast-Sparse Mode (PIM-SM)
  - RFC2362 defines packet formats for PIM-SM. draft-ietf-pim-ipv6-01.txt is written based on this.
- RFC2373: IPv6 Addressing Architecture
  - supports node required addresses, and conforms to the scope requirement.
- RFC2374: An IPv6 Aggregatable Global Unicast Address Format
  - supports 64-bit length of Interface ID.
- RFC2375: IPv6 Multicast Address Assignments
  - Userland applications use the well-known addresses assigned in the RFC.
- RFC2428: FTP Extensions for IPv6 and NATs
  - RFC2428 is preferred over RFC1639. FTP clients will first try RFC2428, then RFC1639 if failed.
- RFC2460: IPv6 specification
- RFC2461: Neighbor discovery for IPv6

    - See 23.5.1.2 in this document for details.
- RFC2462: IPv6 Stateless Address Autoconfiguration
    - See 23.5.1.4 in this document for details.
- RFC2463: ICMPv6 for IPv6 specification
    - See 23.5.1.9 in this document for details.
- RFC2464: Transmission of IPv6 Packets over Ethernet Networks
- RFC2465: MIB for IPv6: Textual Conventions and General Group
    - Necessary statistics are gathered by the kernel. Actual IPv6 MIB support is provided as a patchkit for ucd-snmp.
- RFC2466: MIB for IPv6: ICMPv6 group
    - Necessary statistics are gathered by the kernel. Actual IPv6 MIB support is provided as patchkit for ucd-snmp.
- RFC2467: Transmission of IPv6 Packets over FDDI Networks
- RFC2497: Transmission of IPv6 packet over ARCnet Networks
- RFC2553: Basic Socket Interface Extensions for IPv6
    - IPv4 mapped address (3.7) and special behavior of IPv6 wildcard bind socket (3.8) are supported. See 23.5.1.12 in this document for details.
- RFC2675: IPv6 Jumbograms
    - See 23.5.1.7 in this document for details.
- RFC2710: Multicast Listener Discovery for IPv6
- RFC2711: IPv6 router alert option
- draft-ietf-ipngwg-router-renum-08: Router renumbering for IPv6
- draft-ietf-ipngwg-icmp-namelookups-02: IPv6 Name Lookups Through ICMP
- draft-ietf-ipngwg-icmp-name-lookups-03: IPv6 Name Lookups Through ICMP
- draft-ietf-pim-ipv6-01.txt: PIM for IPv6
    - pim6dd(8) implements dense mode. pim6sd(8) implements sparse mode.
- draft-itojun-ipv6-tcp-to-anycast-00: Disconnecting TCP connection toward IPv6 anycast address
- draft-yamamoto-wideipv6-comm-model-00
    - See 23.5.1.6 in this document for details.
- draft-ietf-ipngwg-scopedaddr-format-00.txt: An Extension of Format for IPv6 Scoped Addresses

8.1.1.2. Neighbor Discovery

Neighbor Discovery is fairly stable. Currently Address Resolution, Duplicated Address Detection, and Neighbor Unreachability Detection are supported. In the near future we will be adding Proxy Neighbor Advertisement support in the kernel and Unsolicited Neighbor Advertisement transmission command as admin tool.

If DAD fails, the address will be marked "duplicated" and message will be generated to syslog (and usually to console). The "duplicated" mark can be checked with ifconfig(8). It is administrators' responsibility to check for and recover from DAD failures. The behavior should be improved in the near future.

Some of the network driver loops multicast packets back to itself, even if instructed not to do so (especially in promiscuous mode). In such cases DAD may fail, because DAD engine sees inbound NS packet (actually from the node itself) and considers it as a sign of duplicate. You may want to look at #if condition marked "heuristics" in sys/netinet6/nd6_nbr.c:nd6_dad_timer() as workaround (note that the code fragment in "heuristics" section is not spec conformant).

Neighbor Discovery specification (RFC2461) does not talk about neighbor cache handling in the

following cases:

1. when there was no neighbor cache entry, node received unsolicited RS/NS/NA/redirect packet without link-layer address
2. neighbor cache handling on medium without link-layer address (we need a neighbor cache entry for IsRouter bit)

For first case, we implemented workaround based on discussions on IETF ipngwg mailing list. For more details, see the comments in the source code and email thread started from (IPng 7155), dated Feb 6 1999.

IPv6 on-link determination rule (RFC2461) is quite different from assumptions in BSD network code. At this moment, no on-link determination rule is supported where default router list is empty (RFC2461, section 5.2, last sentence in 2nd paragraph - note that the spec misuse the word "host" and "node" in several places in the section).

To avoid possible DoS attacks and infinite loops, only 10 options on ND packet is accepted now. Therefore, if you have 20 prefix options attached to RA, only the first 10 prefixes will be recognized. If this troubles you, please ask it on FREEBSD-CURRENT mailing list and/or modify nd6_maxndopt in sys/netinet6/nd6.c. If there are high demands we may provide sysctl knob for the variable.

8.1.1.3. Scope Index

IPv6 uses scoped addresses. Therefore, it is very important to specify scope index (interface index for link-local address, or site index for site-local address) with an IPv6 address. Without scope index, scoped IPv6 address is ambiguous to the kernel, and kernel will not be able to determine the outbound interface for a packet.

Ordinary userland applications should use advanced API (RFC2292) to specify scope index, or interface index. For similar purpose, sin6_scope_id member in sockaddr_in6 structure is defined in RFC2553. However, the semantics for sin6_scope_id is rather vague. If you care about portability of your application, we suggest you to use advanced API rather than sin6_scope_id.

In the kernel, an interface index for link-local scoped address is embedded into 2nd 16bit-word (3rd and 4th byte) in IPv6 address. For example, you may see something like:

```
fe80:1::200:f8ff:fe01:6317
```

in the routing table and interface address structure (struct in6_ifaddr). The address above is a link-local unicast address which belongs to a network interface whose interface identifier is 1. The embedded index enables us to identify IPv6 link local addresses over multiple interfaces effectively and with only a little code change.

Routing daemons and configuration programs, like route6d(8) and ifconfig(8), will need to manipulate the "embedded" scope index. These programs use routing sockets and ioctls (like SIOCGIFADDR_IN6) and the kernel API will return IPv6 addresses with 2nd 16bit-word filled in. The APIs are for manipulating kernel internal structure. Programs that use these APIs have to be prepared about differences in kernels anyway.

When you specify scoped address to the command line, NEVER write the embedded form (such as ff02:1::1 or fe80:2::fedc). This is not supposed to work. Always use standard form, like ff02::1 or fe80::fedc, with command line option for specifying interface (like ping6 -I ne0 ff02::1). In general, if a command does not have command line option to specify outgoing interface, that command is not ready to accept scoped address. This may seem to be opposite from IPv6' s premise to support "dentist office" situation. We believe that specifications need some improvements for this.

Some of the userland tools support extended numeric IPv6 syntax, as documented in draft-ietf-ipngwg-scopedaddr-format-00.txt. You can specify outgoing link, by using name of the outgoing interface like "fe80::1%ne0". This way you will be able to specify link-local scoped address without much trouble.

To use this extension in your program, you will need to use getaddrinfo(3), and getnameinfo(3) with NI_WITHSCOPEID. The implementation currently assumes 1-to-1 relationship between a link and an interface, which is stronger than what specs say.

8.1.1.4. Plug and Play

Most of the IPv6 stateless address autoconfiguration is implemented in the kernel. Neighbor Discovery functions are implemented in the kernel as a whole. Router Advertisement (RA) input for hosts is implemented in the kernel. Router Solicitation (RS) output for endhosts, RS input for routers, and RA output for routers are implemented in the userland.

8.1.1.4.1. Assignment of link-local, and special addresses

IPv6 link-local address is generated from IEEE802 address (Ethernet MAC address). Each of interface is assigned an IPv6 link-local address automatically, when the interface becomes up (IFF_UP). Also, direct route for the link-local address is added to routing table.

Here is an output of netstat command:

```
Internet6:
Destination        Gateway         Flags     Netif Expire
fe80:1::%ed0/64    link#1          UC        ed0
fe80:2::%ep0/64    link#2          UC        ep0
```

Interfaces that has no IEEE802 address (pseudo interfaces like tunnel interfaces, or ppp interfaces) will borrow IEEE802 address from other interfaces, such as Ethernet interfaces, whenever possible. If there is no IEEE802 hardware attached, a last resort pseudo-random value, MD5(hostname), will be used as source of link-local address. If it is not suitable for your usage, you will need to configure the link-local address manually.

If an interface is not capable of handling IPv6 (such as lack of multicast support), link-local address will not be assigned to that interface. See section 2 for details.

Each interface joins the solicited multicast address and the link-local all-nodes multicast addresses (e.g., fe80::1:ff01:6317 and ff02::1, respectively, on the link the interface is attached). In addition to a link-local address, the loopback address (::1) will be assigned to the loopback interface. Also, ::1/128 and ff01::/32 are automatically added to routing table, and loopback interface joins node-local multicast group ff01::1.

8.1.1.4.2. Stateless address autoconfiguration on Hosts

In IPv6 specification, nodes are separated into two categories: routers and hosts. Routers forward packets addressed to others, hosts does not forward the packets. net.inet6.ip6.forwarding defines whether this node is router or host (router if it is 1, host if it is 0).

When a host hears Router Advertisement from the router, a host may autoconfigure itself by stateless address autoconfiguration. This behavior can be controlled by net.inet6.ip6.accept_rtadv (host autoconfigures itself if it is set to 1). By autoconfiguration, network address prefix for the receiving interface (usually global address prefix) is added. Default route is also configured. Routers periodically generate Router Advertisement packets. To request an adjacent router to generate RA packet, a host can transmit Router Solicitation. To generate a RS packet at any time, use the rtsol command. rtsold(8) daemon is also available. rtsold(8) generates Router Solicitation whenever necessary, and it works great for nomadic usage (notebooks/laptops). If one wishes to ignore Router Advertisements, use sysctl to set net.inet6.ip6.accept_rtadv to 0.

To generate Router Advertisement from a router, use the rtadvd(8) daemon.

Note that, IPv6 specification assumes the following items, and nonconforming cases are left unspecified:

- Only hosts will listen to router advertisements
- Hosts have single network interface (except loopback)

Therefore, this is unwise to enable net.inet6.ip6.accept_rtadv on routers, or multi-interface host. A misconfigured node can behave strange (nonconforming configuration allowed for those who would like to do some experiments).

To summarize the sysctl knob:

accept_rtadv	forwarding	role of the node
0	0	host (to be manually configured)
0	1	router
1	0	autoconfigured host (spec assumes that host has single interface only, autoconfigured host with multiple interface is out-of-scope)
1	1	invalid, or experimental (out-of-scope of spec)

RFC2462 has validation rule against incoming RA prefix information option, in 5.5.3 (e). This is to protect hosts from malicious (or misconfigured) routers that advertise very short prefix lifetime. There was an update from Jim Bound to ipngwg mailing list (look for "(ipng 6712)" in the archive) and it is implemented Jim’ s update.

See 23.5.1.2 in the document for relationship between DAD and autoconfiguration.

8.1.1.5. Generic Tunnel Interface

GIF (Generic InterFace) is a pseudo interface for configured tunnel. Details are described in gif(4). Currently

- v6 in v6
- v6 in v4
- v4 in v6
- v4 in v4

are available. Use gifconfig(8) to assign physical (outer) source and destination address to gif interfaces. Configuration that uses same address family for inner and outer IP header (v4 in v4, or v6 in v6) is dangerous. It is very easy to configure interfaces and routing tables to perform infinite level of tunneling. Please be warned.

gif can be configured to be ECN-friendly. See 23.5.4.5 for ECN-friendliness of tunnels, and gif(4) for how to configure.

If you would like to configure an IPv4-in-IPv6 tunnel with gif interface, read gif(4) carefully. You will need to remove IPv6 link-local address automatically assigned to the gif interface.

8.1.1.6. Source Address Selection

Current source selection rule is scope oriented (there are some exceptions - see below). For a given destination, a source IPv6 address is selected by the following rule:

1. If the source address is explicitly specified by the user (e.g., via the advanced API), the specified address is used.
2. If there is an address assigned to the outgoing interface (which is usually determined by looking up the routing table) that has the same scope as the destination address, the address is used.

   This is the most typical case.
3. If there is no address that satisfies the above condition, choose a global address assigned to one of the interfaces on the sending node.
4. If there is no address that satisfies the above condition, and destination address is site local scope, choose a site local address assigned to one of the interfaces on the sending node.
5. If there is no address that satisfies the above condition, choose the address associated with the routing table entry for the destination. This is the last resort, which may cause scope violation.

For instance, ::1 is selected for ff01::1, fe80:1::200:f8ff:fe01:6317 for fe80:1::2a0:24ff:feab:839b (note that embedded interface index - described in 23.5.1.3 - helps us choose the right source address. Those embedded indices will not be on the wire). If the outgoing interface has multiple address for the scope, a source is selected longest match basis (rule 3). Suppose 2001:0DB8:808:1:200:f8ff:fe01:6317 and 2001:0DB8:9:124:200:f8ff:fe01:6317 are given to the outgoing interface. 2001:0DB8:808:1:200:f8ff:fe01:6317 is chosen as the source for the destination 2001:0DB8:800::1.

Note that the above rule is not documented in the IPv6 spec. It is considered "up to implementation" item. There are some cases where we do not use the above rule. One example is connected TCP session, and we use the address kept in tcb as the source. Another example is source address for Neighbor Advertisement. Under the spec (RFC2461 7.2.2) NA’ s source should be the target address of the corresponding NS’ s target. In this case we follow the spec rather than the above longest-match rule.

For new connections (when rule 1 does not apply), deprecated addresses (addresses with preferred lifetime = 0) will not be chosen as source address if other choices are available. If no other choices are available, deprecated address will be used as a last resort. If there are multiple choice of deprecated addresses, the above scope rule will be used to choose from those deprecated addresses. If you would like to prohibit the use of deprecated address for some reason, configure net.inet6.ip6.use_deprecated to 0. The issue related to deprecated address is described in RFC2462 5.5.4 (NOTE: there is some debate underway in IETF ipngwg on how to use "deprecated" address).

8.1.1.7. Jumbo Payload

The Jumbo Payload hop-by-hop option is implemented and can be used to send IPv6 packets with payloads longer than 65,535 octets. But currently no physical interface whose MTU is more than 65,535 is supported, so such payloads can be seen only on the loopback interface (i.e., lo0).

If you want to try jumbo payloads, you first have to reconfigure the kernel so that the MTU of the loopback interface is more than 65,535 bytes; add the following to the kernel configuration file:

```
options "LARGE_LOMTU" #To test jumbo payload
```

and recompile the new kernel.

Then you can test jumbo payloads by the ping6(8) command with -b and -s options. The -b option must be specified to enlarge the size of the socket buffer and the -s option specifies the length of the packet, which should be more than 65,535. For example, type as follows:

```
% ping6 -b 70000 -s 68000 ::1
```

The IPv6 specification requires that the Jumbo Payload option must not be used in a packet that carries a fragment header. If this condition is broken, an ICMPv6 Parameter Problem message must be sent to the sender. specification is followed, but you cannot usually see an ICMPv6 error caused

by this requirement.

When an IPv6 packet is received, the frame length is checked and compared to the length specified in the payload length field of the IPv6 header or in the value of the Jumbo Payload option, if any. If the former is shorter than the latter, the packet is discarded and statistics are incremented. You can see the statistics as output of netstat(8) command with `-s -p ip6' option:

```
% netstat -s -p ip6
    ip6:
     (snip)
     1 with data size < data length
```

So, kernel does not send an ICMPv6 error unless the erroneous packet is an actual Jumbo Payload, that is, its packet size is more than 65,535 bytes. As described above, currently no physical interface with such a huge MTU is supported, so it rarely returns an ICMPv6 error.

TCP/UDP over jumbogram is not supported at this moment. This is because we have no medium (other than loopback) to test this. Contact us if you need this.

IPsec does not work on jumbograms. This is due to some specification twists in supporting AH with jumbograms (AH header size influences payload length, and this makes it real hard to authenticate inbound packet with jumbo payload option as well as AH).

There are fundamental issues in *BSD support for jumbograms. We would like to address those, but we need more time to finalize these. To name a few:

- mbuf pkthdr.len field is typed as "int" in 4.4BSD, so it will not hold jumbogram with len > 2G on 32bit architecture CPUs. If we would like to support jumbogram properly, the field must be expanded to hold 4G + IPv6 header + link-layer header. Therefore, it must be expanded to at least int64_t (u_int32_t is NOT enough).
- We mistakingly use "int" to hold packet length in many places. We need to convert them into larger integral type. It needs a great care, as we may experience overflow during packet length computation.
- We mistakingly check for ip6_plen field of IPv6 header for packet payload length in various places. We should be checking mbuf pkthdr.len instead. ip6_input() will perform sanity check on jumbo payload option on input, and we can safely use mbuf pkthdr.len afterwards.
- TCP code needs a careful update in bunch of places, of course.

8.1.1.8. Loop Prevention in Header Processing

IPv6 specification allows arbitrary number of extension headers to be placed onto packets. If we implement IPv6 packet processing code in the way BSD IPv4 code is implemented, kernel stack may overflow due to long function call chain. sys/netinet6 code is carefully designed to avoid kernel stack overflow. Because of this, sys/netinet6 code defines its own protocol switch structure, as "struct ip6protosw" (see netinet6/ip6protosw.h). There is no such update to IPv4 part (sys/netinet) for compatibility, but small change is added to its pr_input() prototype. So "struct ipprotosw" is also defined. Because of this, if you receive IPsec-over-IPv4 packet with massive number of IPsec headers, kernel stack may blow up. IPsec-over-IPv6 is okay. (Off-course, for those all IPsec headers to be processed, each such IPsec header must pass each IPsec check. So an anonymous attacker will not be able to do such an attack.)

8.1.1.9. ICMPv6

After RFC2463 was published, IETF ipngwg has decided to disallow ICMPv6 error packet against ICMPv6 redirect, to prevent ICMPv6 storm on a network medium. This is already implemented into the kernel.

8.1.1.10. Applications

For userland programming, we support IPv6 socket API as specified in RFC2553, RFC2292 and upcoming Internet drafts.

TCP/UDP over IPv6 is available and quite stable. You can enjoy telnet(1), ftp(1), rlogin(1), rsh(1), ssh(1), etc. These applications are protocol independent. That is, they automatically chooses IPv4 or IPv6 according to DNS.

8.1.1.11. Kernel Internals

While ip_forward() calls ip_output(), ip6_forward() directly calls if_output() since routers must not divide IPv6 packets into fragments.

ICMPv6 should contain the original packet as long as possible up to 1280. UDP6/IP6 port unreach, for instance, should contain all extension headers and the unchanged UDP6 and IP6 headers. So, all IP6 functions except TCP never convert network byte order into host byte order, to save the original packet.

tcp_input(), udp6_input() and icmp6_input() can not assume that IP6 header is preceding the transport headers due to extension headers. So, in6_cksum() was implemented to handle packets whose IP6 header and transport header is not continuous. TCP/IP6 nor UDP6/IP6 header structures do not exist for checksum calculation.

To process IP6 header, extension headers and transport headers easily, network drivers are now required to store packets in one internal mbuf or one or more external mbufs. A typical old driver prepares two internal mbufs for 96 - 204 bytes data, however, now such packet data is stored in one external mbuf.

netstat -s -p ip6 tells you whether or not your driver conforms such requirement. In the following example, "cce0" violates the requirement. (For more information, refer to Section 2.)

```
Mbuf statistics:
        317 one mbuf
        two or more mbuf::
            lo0 = 8
      cce0 = 10
        3282 one ext mbuf
        0 two or more ext mbuf
```

Each input function calls IP6_EXTHDR_CHECK in the beginning to check if the region between IP6 and its header is continuous. IP6_EXTHDR_CHECK calls m_pullup() only if the mbuf has M_LOOP flag, that is, the packet comes from the loopback interface. m_pullup() is never called for packets coming from physical network interfaces.

Both IP and IP6 reassemble functions never call m_pullup().

8.1.1.12. IPv4 Mapped Address and IPv6 Wildcard Socket

RFC2553 describes IPv4 mapped address (3.7) and special behavior of IPv6 wildcard bind socket (3.8). The spec allows you to:

- Accept IPv4 connections by AF_INET6 wildcard bind socket.
- Transmit IPv4 packet over AF_INET6 socket by using special form of the address like ::ffff:10.1.1.1.

but the spec itself is very complicated and does not specify how the socket layer should behave.

Here we call the former one "listening side" and the latter one "initiating side", for reference purposes.

You can perform wildcard bind on both of the address families, on the same port.

The following table show the behavior of FreeBSD 4.x.

```
listening side       initiating side
        (AF_INET6 wildcard     (connection to ::ffff:10.1.1.1)
        socket gets IPv4 conn.)
        ---              ---
FreeBSD 4.x   configurable        supported
        default: enabled
```

The following sections will give you more details, and how you can configure the behavior.

Comments on listening side:

It looks that RFC2553 talks too little on wildcard bind issue, especially on the port space issue, failure mode and relationship between AF_INET/INET6 wildcard bind. There can be several separate interpretation for this RFC which conform to it but behaves differently. So, to implement portable application you should assume nothing about the behavior in the kernel. Using getaddrinfo(3) is the safest way. Port number space and wildcard bind issues were discussed in detail on ipv6imp mailing list, in mid March 1999 and it looks that there is no concrete consensus (means, up to implementers). You may want to check the mailing list archives.

If a server application would like to accept IPv4 and IPv6 connections, there will be two alternatives.

One is using AF_INET and AF_INET6 socket (you will need two sockets). Use getaddrinfo(3) with AI_PASSIVE into ai_flags, and socket(2) and bind(2) to all the addresses returned. By opening multiple sockets, you can accept connections onto the socket with proper address family. IPv4 connections will be accepted by AF_INET socket, and IPv6 connections will be accepted by AF_INET6 socket.

Another way is using one AF_INET6 wildcard bind socket. Use getaddrinfo(3) with AI_PASSIVE into ai_flags and with AF_INET6 into ai_family, and set the 1st argument hostname to NULL. And socket(2) and bind(2) to the address returned. (should be IPv6 unspecified addr). You can accept either of IPv4 and IPv6 packet via this one socket.

To support only IPv6 traffic on AF_INET6 wildcard binded socket portably, always check the peer address when a connection is made toward AF_INET6 listening socket. If the address is IPv4 mapped address, you may want to reject the connection. You can check the condition by using IN6_IS_ADDR_V4MAPPED() macro.

To resolve this issue more easily, there is system dependent setsockopt(2) option, IPV6_BINDV6ONLY, used like below.

```
int on;

setsockopt(s, IPPROTO_IPV6, IPV6_BINDV6ONLY,
    (char *)&on, sizeof (on)) < 0));
```

When this call succeed, then this socket only receive IPv6 packets.

Comments on initiating side:

Advise to application implementers: to implement a portable IPv6 application (which works on multiple IPv6 kernels), we believe that the following is the key to the success:

- NEVER hardcode AF_INET nor AF_INET6.
- Use getaddrinfo(3) and getnameinfo(3) throughout the system. Never use gethostby*(), getaddrby*(), inet_*() or getipnodeby*(). (To update existing applications to be IPv6 aware easily, sometime getipnodeby*() will be useful. But if possible, try to rewrite the code to use getaddrinfo(3) and getnameinfo(3).)
- If you would like to connect to destination, use getaddrinfo(3) and try all the destination returned, like telnet(1) does.
- Some of the IPv6 stack is shipped with buggy getaddrinfo(3). Ship a minimal working version with your application and use that as last resort.

If you would like to use AF_INET6 socket for both IPv4 and IPv6 outgoing connection, you will need to use getipnodebyname(3). When you would like to update your existing application to be IPv6 aware with minimal effort, this approach might be chosen. But please note that it is a temporal solution, because getipnodebyname(3) itself is not recommended as it does not handle scoped IPv6 addresses at all. For IPv6 name resolution, getaddrinfo(3) is the preferred API. So you should rewrite your application to use getaddrinfo(3), when you get the time to do it.

When writing applications that make outgoing connections, story goes much simpler if you treat AF_INET and AF_INET6 as totally separate address family. {set,get}sockopt issue goes simpler, DNS issue will be made simpler. We do not recommend you to rely upon IPv4 mapped address.

8.1.1.12.1. unified tcp and inpcb code

FreeBSD 4.x uses shared tcp code between IPv4 and IPv6 (from sys/netinet/tcp*) and separate udp4/6 code. It uses unified inpcb structure.

The platform can be configured to support IPv4 mapped address. Kernel configuration is summarized as follows:

- By default, AF_INET6 socket will grab IPv4 connections in certain condition, and can initiate connection to IPv4 destination embedded in IPv4 mapped IPv6 address.
- You can disable it on entire system with sysctl like below.

  sysctl net.inet6.ip6.mapped_addr=0

8.1.1.12.1.1. Listening Side

Each socket can be configured to support special AF_INET6 wildcard bind (enabled by default). You can disable it on each socket basis with setsockopt(2) like below.

```
int on;

setsockopt(s, IPPROTO_IPV6, IPV6_BINDV6ONLY,
    (char *)&on, sizeof (on)) < 0));
```

Wildcard AF_INET6 socket grabs IPv4 connection if and only if the following conditions are satisfied:

- there is no AF_INET socket that matches the IPv4 connection
- the AF_INET6 socket is configured to accept IPv4 traffic, i.e., getsockopt(IPV6_BINDV6ONLY) returns 0.

There is no problem with open/close ordering.

8.1.1.12.1.2. Initiating Side

FreeBSD 4.x supports outgoing connection to IPv4 mapped address (::ffff:10.1.1.1), if the node is configured to support IPv4 mapped address.

8.1.1.13. sockaddr_storage

When RFC2553 was about to be finalized, there was discussion on how struct sockaddr_storage members are named. One proposal is to prepend "" to the members (like "ss_len") as they should not be touched. The other proposal was not to prepend it (like "ss_len") as we need to touch those members directly. There was no clear consensus on it.

As a result, RFC2553 defines struct sockaddr_storage as follows:

```
struct sockaddr_storage {
  u_char  __ss_len;   /* address length */
  u_char  __ss_family;    /* address family */
  /* and bunch of padding */
};
```

On the contrary, XNET draft defines as follows:

```
struct sockaddr_storage {
  u_char  ss_len;    /* address length */
  u_char  ss_family;  /* address family */
  /* and bunch of padding */
};
```

In December 1999, it was agreed that RFC2553bis should pick the latter (XNET) definition.

Current implementation conforms to XNET definition, based on RFC2553bis discussion.

If you look at multiple IPv6 implementations, you will be able to see both definitions. As an userland programmer, the most portable way of dealing with it is to:

1. ensure ss_family and/or ss_len are available on the platform, by using GNU autoconf,
2. have -Dss_family=ss_family to unify all occurrences (including header file) into ss_family, or
3. never touch __ss_family. cast to sockaddr * and use sa_family like:

```
struct sockaddr_storage ss;
family = ((struct sockaddr *)&ss)->sa_family
```

8.1.2. Network Drivers

Now following two items are required to be supported by standard drivers:

1. mbuf clustering requirement. In this stable release, we changed MINCLSIZE into MHLEN+1 for all the operating systems in order to make all the drivers behave as we expect.
2. multicast. If ifmcstat(8) yields no multicast group for a interface, that interface has to be patched.

If any of the drivers do not support the requirements, then the drivers cannot be used for IPv6 and/or IPsec communication. If you find any problem with your card using IPv6/IPsec, then, please report it to the FreeBSD problem reports 郵遞論壇.

(NOTE: In the past we required all PCMCIA drivers to have a call to in6_ifattach(). We have no such requirement any more)

8.1.3. Translator

We categorize IPv4/IPv6 translator into 4 types:

- Translator A --- It is used in the early stage of transition to make it possible to establish a connection from an IPv6 host in an IPv6 island to an IPv4 host in the IPv4 ocean.
- Translator B --- It is used in the early stage of transition to make it possible to establish a connection from an IPv4 host in the IPv4 ocean to an IPv6 host in an IPv6 island.
- Translator C --- It is used in the late stage of transition to make it possible to establish a connection from an IPv4 host in an IPv4 island to an IPv6 host in the IPv6 ocean.
- Translator D --- It is used in the late stage of transition to make it possible to establish a connection from an IPv6 host in the IPv6 ocean to an IPv4 host in an IPv4 island.

8.1.4. IPsec

IPsec is mainly organized by three components.

1. Policy Management
2. Key Management
3. AH and ESP handling

8.1.4.1. Policy Management

The kernel implements experimental policy management code. There are two way to manage security policy. One is to configure per-socket policy using setsockopt(2). In this cases, policy configuration is described in ipsec_set_policy(3). The other is to configure kernel packet filter-based policy using PF_KEY interface, via setkey(8).

The policy entry is not re-ordered with its indexes, so the order of entry when you add is very significant.

8.1.4.2. Key Management

The key management code implemented in this kit (sys/netkey) is a home-brew PFKEY v2 implementation. This conforms to RFC2367.

The home-brew IKE daemon, "racoon" is included in the kit (kame/kame/racoon). Basically you will need to run racoon as daemon, then set up a policy to require keys (like ping -P 'out ipsec esp/transport//use'). The kernel will contact racoon daemon as necessary to exchange keys.

8.1.4.3. AH and ESP Handling

IPsec module is implemented as "hooks" to the standard IPv4/IPv6 processing. When sending a packet, ip{,6}_output() checks if ESP/AH processing is required by checking if a matching SPD (Security Policy Database) is found. If ESP/AH is needed, {esp,ah}{4,6}_output() will be called and mbuf will be updated accordingly. When a packet is received, {esp,ah}4_input() will be called based on protocol number, i.e., (*inetsw[proto])(). {esp,ah}4_input() will decrypt/check authenticity of the packet, and strips off daisy-chained header and padding for ESP/AH. It is safe to strip off the ESP/AH header on packet reception, since we will never use the received packet in "as is" form.

By using ESP/AH, TCP4/6 effective data segment size will be affected by extra daisy-chained headers inserted by ESP/AH. Our code takes care of the case.

Basic crypto functions can be found in directory "sys/crypto". ESP/AH transform are listed in {esp,ah}_core.c with wrapper functions. If you wish to add some algorithm, add wrapper function in {esp,ah}_core.c, and add your crypto algorithm code into sys/crypto.

Tunnel mode is partially supported in this release, with the following restrictions:

- IPsec tunnel is not combined with GIF generic tunneling interface. It needs a great care because we may create an infinite loop between ip_output() and tunnelifp→if_output(). Opinion varies if it is better to unify them, or not.
- MTU and Don’ t Fragment bit (IPv4) considerations need more checking, but basically works fine.
- Authentication model for AH tunnel must be revisited. We will need to improve the policy management engine, eventually.

8.1.4.4. Conformance to RFCs and IDs

The IPsec code in the kernel conforms (or, tries to conform) to the following standards:

"old IPsec" specification documented in rfc182[5-9].txt

"new IPsec" specification documented in rfc240[1-6].txt, rfc241[01].txt, rfc2451.txt and draft-mcdonald-simple-ipsec-api-01.txt (draft expired, but you can take from ftp://ftp.kame.net/pub/internet-drafts/). (NOTE: IKE specifications, rfc241[7-9].txt are implemented in userland, as "racoon" IKE daemon)

Currently supported algorithms are:

- old IPsec AH
  - null crypto checksum (no document, just for debugging)
  - keyed MD5 with 128bit crypto checksum (rfc1828.txt)
  - keyed SHA1 with 128bit crypto checksum (no document)
  - HMAC MD5 with 128bit crypto checksum (rfc2085.txt)
  - HMAC SHA1 with 128bit crypto checksum (no document)
- old IPsec ESP
  - null encryption (no document, similar to rfc2410.txt)
  - DES-CBC mode (rfc1829.txt)
- new IPsec AH
  - null crypto checksum (no document, just for debugging)
  - keyed MD5 with 96bit crypto checksum (no document)
  - keyed SHA1 with 96bit crypto checksum (no document)
  - HMAC MD5 with 96bit crypto checksum (rfc2403.txt)
  - HMAC SHA1 with 96bit crypto checksum (rfc2404.txt)
- new IPsec ESP
  - null encryption (rfc2410.txt)
  - DES-CBC with derived IV (draft-ietf-ipsec-ciph-des-derived-01.txt, draft expired)
  - DES-CBC with explicit IV (rfc2405.txt)
  - 3DES-CBC with explicit IV (rfc2451.txt)
  - BLOWFISH CBC (rfc2451.txt)
  - CAST128 CBC (rfc2451.txt)
  - RC5 CBC (rfc2451.txt)

- each of the above can be combined with:
  - ESP authentication with HMAC-MD5(96bit)
  - ESP authentication with HMAC-SHA1(96bit)

The following algorithms are NOT supported:

- old IPsec AH
  - HMAC MD5 with 128bit crypto checksum + 64bit replay prevention (rfc2085.txt)
  - keyed SHA1 with 160bit crypto checksum + 32bit padding (rfc1852.txt)

IPsec (in kernel) and IKE (in userland as "racoon") has been tested at several interoperability test events, and it is known to interoperate with many other implementations well. Also, current IPsec implementation as quite wide coverage for IPsec crypto algorithms documented in RFC (we cover algorithms without intellectual property issues only).

8.1.4.5. ECN Consideration on IPsec Tunnels

ECN-friendly IPsec tunnel is supported as described in draft-ipsec-ecn-00.txt.

Normal IPsec tunnel is described in RFC2401. On encapsulation, IPv4 TOS field (or, IPv6 traffic class field) will be copied from inner IP header to outer IP header. On decapsulation outer IP header will be simply dropped. The decapsulation rule is not compatible with ECN, since ECN bit on the outer IP TOS/traffic class field will be lost.

To make IPsec tunnel ECN-friendly, we should modify encapsulation and decapsulation procedure. This is described in http://www.aciri.org/floyd/papers/draft-ipsec-ecn-00.txt, chapter 3.

IPsec tunnel implementation can give you three behaviors, by setting net.inet.ipsec.ecn (or net.inet6.ipsec6.ecn) to some value:

- RFC2401: no consideration for ECN (sysctl value -1)
- ECN forbidden (sysctl value 0)
- ECN allowed (sysctl value 1)

Note that the behavior is configurable in per-node manner, not per-SA manner (draft-ipsec-ecn-00 wants per-SA configuration, but it looks too much for me).

The behavior is summarized as follows (see source code for more detail):

```
encapsulate              decapsulate
        ---                  ---
RFC2401      copy all TOS bits          drop TOS bits on outer
        from inner to outer.        (use inner TOS bits as is)

ECN forbidden   copy TOS bits except for ECN    drop TOS bits on outer
        (masked with 0xfc) from inner   (use inner TOS bits as is)
        to outer.  set ECN bits to 0.

ECN allowed    copy TOS bits except for ECN    use inner TOS bits with some
        CE (masked with 0xfe) from     change.  if outer ECN CE bit
        inner to outer.            is 1, enable ECN CE bit on
        set ECN CE bit to 0.         the inner.
```

General strategy for configuration is as follows:

- if both IPsec tunnel endpoint are capable of ECN-friendly behavior, you should better configure both end to "ECN allowed" (sysctl value 1).
- if the other end is very strict about TOS bit, use "RFC2401" (sysctl value -1).
- in other cases, use "ECN forbidden" (sysctl value 0).

The default behavior is "ECN forbidden" (sysctl value 0).

For more information, please refer to:

http://www.aciri.org/floyd/papers/draft-ipsec-ecn-00.txt, RFC2481 (Explicit Congestion Notification), src/sys/netinet6/{ah,esp}_input.c

(Thanks goes to Kenjiro Cho kjc@csl.sony.co.jp for detailed analysis)

8.1.4.6. Interoperability

Here are (some of) platforms that KAME code have tested IPsec/IKE interoperability in the past. Note that both ends may have modified their implementation, so use the following list just for reference purposes.

Altiga, Ashley-laurent (vpcom.com), Data Fellows (F-Secure), Ericsson ACC, FreeS/WAN, HITACHI, IBM AIX®, IIJ, Intel, Microsoft® Windows NT®, NIST (linux IPsec + plutoplus), Netscreen, OpenBSD, RedCreek, Routerware, SSH, Secure Computing, Soliton, Toshiba, VPNet, Yamaha RT100i

Part III: Kernel(核心)

Chapter 9. Building and Installing a FreeBSD Kernel

Being a kernel developer requires understanding of the kernel build process. To debug the FreeBSD kernel it is required to be able to build one. There are two known ways to do so:

The supported procedure to build and install a kernel is documented in the Building and Installing a Custom Kernel chapter of the FreeBSD Handbook.

It is supposed that the reader of this chapter is familiar with the information described in the Building and Installing a Custom Kernel chapter of the FreeBSD Handbook. If this is not the case, please read through the above mentioned chapter to understand how the build process works.

9.1. Building the Faster but Brittle Way

Building the kernel this way may be useful when working on the kernel code and it may actually be faster than the documented procedure when only a single option or two were tweaked in the kernel configuration file. On the other hand, it might lead to unexpected kernel build breakage.

1. Run config(8) to generate the kernel source code:

```
# /usr/sbin/config MYKERNEL
```

2. Change into the build directory. config(8) will print the name of this directory after being run as above.

```
# cd ../compile/MYKERNEL
```

3. Compile the kernel:

```
# make depend
# make
```

4. Install the new kernel:

```
# make install
```

Chapter 10. Kernel Debugging

10.1. Obtaining a Kernel Crash Dump

When running a development kernel (e.g., FreeBSD-CURRENT), such as a kernel under extreme conditions (e.g., very high load averages, tens of thousands of connections, exceedingly high number of concurrent users, hundreds of jail(8)s, etc.), or using a new feature or device driver on FreeBSD-STABLE (e.g., PAE), sometimes a kernel will panic. In the event that it does, this chapter will demonstrate how to extract useful information out of a crash.

A system reboot is inevitable once a kernel panics. Once a system is rebooted, the contents of a system's physical memory (RAM) is lost, as well as any bits that are on the swap device before the panic. To preserve the bits in physical memory, the kernel makes use of the swap device as a temporary place to store the bits that are in RAM across a reboot after a crash. In doing this, when FreeBSD boots after a crash, a kernel image can now be extracted and debugging can take place.

A swap device that has been configured as a dump device still acts as a swap device. Dumps to non-swap devices (such as tapes or CDRWs, for example) are not supported at this time. A "swap device" is synonymous with a "swap partition."

Several types of kernel crash dumps are available:

Full memory dumps
: Hold the complete contents of physical memory.

Minidumps
: Hold only memory pages in use by the kernel (FreeBSD 6.2 and higher).

Textdumps
: Hold captured, scripted, or interactive debugger output (FreeBSD 7.1 and higher).

Minidumps are the default dump type as of FreeBSD 7.0, and in most cases will capture all necessary information present in a full memory dump, as most problems can be isolated only using kernel state.

10.1.1. Configuring the Dump Device

Before the kernel will dump the contents of its physical memory to a dump device, a dump device must be configured. A dump device is specified by using the dumpon(8) command to tell the kernel where to save kernel crash dumps. The dumpon(8) program must be called after the swap partition has been configured with swapon(8). This is normally handled by setting the dumpdev variable in rc.conf(5) to the path of the swap device (the recommended way to extract a kernel dump) or AUTO to use the first configured swap device. The default for dumpdev is AUTO in HEAD, and changed to NO on RELENG_* branches (except for RELENG_7, which was left set to AUTO). On FreeBSD 9.0-RELEASE and later versions, bsdinstall will ask whether crash dumps should be enabled on the target system during the install process.

Check /etc/fstab or swapinfo(8) for a list of swap devices.

Make sure the dumpdir specified in rc.conf(5) exists before a kernel crash!

```
# mkdir /var/crash
# chmod 700 /var/crash
```

Also, remember that the contents of /var/crash is sensitive and very likely contains confidential information such as passwords.

10.1.2. Extracting a Kernel Dump

Once a dump has been written to a dump device, the dump must be extracted before the swap device is mounted. To extract a dump from a dump device, use the savecore(8) program. If dumpdev has been set in rc.conf(5), savecore(8) will be called automatically on the first multi-user boot after the crash and before the swap device is mounted. The location of the extracted core is placed in the rc.conf(5) value dumpdir, by default /var/crash and will be named vmcore.0.

In the event that there is already a file called vmcore.0 in /var/crash (or whatever dumpdir is set to), the kernel will increment the trailing number for every crash to avoid overwriting an existing vmcore (e.g., vmcore.1). savecore(8) will always create a symbolic link to named vmcore.last in /var/crash after a dump is saved. This symbolic link can be used to locate the name of the most recent dump.

The crashinfo(8) utility generates a text file containing a summary of information from a full memory dump or minidump. If dumpdev has been set in rc.conf(5), crashinfo(8) will be invoked automatically after savecore(8). The output is saved to a file in dumpdir named core.txt.N.

If you are testing a new kernel but need to boot a different one in order to get your system up and running again, boot it only into single user mode using the -s flag at the boot prompt, and then perform the following steps:

```
# fsck -p
# mount -a -t ufs      # make sure /var/crash is writable
# savecore /var/crash /dev/ad0s1b
# exit                 # exit to multi-user
```

This instructs savecore(8) to extract a kernel dump from /dev/ad0s1b and place the contents in /var/crash. Do not forget to make sure the destination directory /var/crash has enough space for the dump. Also, do not forget to specify the correct path to your swap device as it is likely different than /dev/ad0s1b!

10.1.3. Testing Kernel Dump Configuration

The kernel includes a sysctl(8) node that requests a kernel panic. This can be used to verify that your system is properly configured to save kernel crash dumps. You may wish to remount existing file systems as read-only in single user mode before triggering the crash to avoid data loss.

```
# shutdown now
...
Enter full pathname of shell or RETURN for /bin/sh:
# mount -a -u -r
# sysctl debug.kdb.panic=1
debug.kdb.panic:panic: kdb_sysctl_panic
...
```

After rebooting, your system should save a dump in /var/crash along with a matching summary from crashinfo(8).

10.2. Debugging a Kernel Crash Dump with kgdb

This section covers kgdb(1). The latest version is included in the devel/gdb.

To enter into the debugger and begin getting information from the dump, start kgdb:

```
# kgdb -n N
```

Where N is the suffix of the vmcore.N to examine. To open the most recent dump use:

```
# kgdb -n last
```

Normally, kgdb(1) should be able to locate the kernel running at the time the dump was generated. If it is not able to locate the correct kernel, pass the pathname of the kernel and dump as two arguments to kgdb:

```
# kgdb /boot/kernel/kernel /var/crash/vmcore.0
```

You can debug the crash dump using the kernel sources just like you can for any other program.

This dump is from a 5.2-BETA kernel and the crash comes from deep within the kernel. The output below has been modified to include line numbers on the left. This first trace inspects the instruction pointer and obtains a back trace. The address that is used on line 41 for the list command is the instruction pointer and can be found on line 17. Most developers will request having at least this information sent to them if you are unable to debug the problem yourself. If, however, you do solve the problem, make sure that your patch winds its way into the source tree via a problem report, mailing lists, or by being able to commit it!

```
 1:# cd /usr/obj/usr/src/sys/KERNCONF
 2:# kgdb kernel.debug /var/crash/vmcore.0
 3:GNU gdb 5.2.1 (FreeBSD)
 4:Copyright 2002 Free Software Foundation, Inc.
 5:GDB is free software, covered by the GNU General Public License, and you are
 6:welcome to change it and/or distribute copies of it under certain conditions.
 7:Type "show copying" to see the conditions.
 8:There is absolutely no warranty for GDB.  Type "show warranty" for details.
 9:This GDB was configured as "i386-undermydesk-freebsd"...
10:panic: page fault
11:panic messages:
12:---
13:Fatal trap 12: page fault while in kernel mode
14:cpuid = 0; apic id = 00
15:fault virtual address   = 0x300
16:fault code:          = supervisor read, page not present
17:instruction pointer    = 0x8:0xc0713860
18:stack pointer        = 0x10:0xdc1d0b70
19:frame pointer        = 0x10:0xdc1d0b7c
20:code segment         = base 0x0, limit 0xfffff, type 0x1b
21:                     = DPL 0, pres 1, def32 1, gran 1
```

```
22:processor eflags      = resume, IOPL = 0
23:current process       = 14394 (uname)
24:trap number           = 12
25:panic: page fault
26     cpuid = 0;
27:Stack backtrace:
28
29:syncing disks, buffers remaining... 2199 2199 panic: mi_switch: switch in a critical
section
30:cpuid = 0;
31:Uptime: 2h43m19s
32:Dumping 255 MB
33: 16 32 48 64 80 96 112 128 144 160 176 192 208 224 240
34:---
35:Reading symbols from /boot/kernel/snd_maestro3.ko...done.
36:Loaded symbols for /boot/kernel/snd_maestro3.ko
37:Reading symbols from /boot/kernel/snd_pcm.ko...done.
38:Loaded symbols for /boot/kernel/snd_pcm.ko
39:#0  doadump () at /usr/src/sys/kern/kern_shutdown.c:240
40:240         dumping++;
41:(kgdb) list *0xc0713860
42:0xc0713860 is in lapic_ipi_wait (/usr/src/sys/i386/i386/local_apic.c:663).
43:658                 incr = 0;
44:659                 delay = 1;
45:660         } else
46:661                 incr = 1;
47:662         for (x = 0; x < delay; x += incr) {
48:663                 if ((lapic->icr_lo & APIC_DELSTAT_MASK) == APIC_DELSTAT_IDLE)
49:664                         return (1);
50:665                 ia32_pause();
51:666         }
52:667         return (0);
53:(kgdb) backtrace
54:#0  doadump () at /usr/src/sys/kern/kern_shutdown.c:240
55:#1  0xc055fd9b in boot (howto=260) at /usr/src/sys/kern/kern_shutdown.c:372
56:#2  0xc056019d in panic () at /usr/src/sys/kern/kern_shutdown.c:550
57:#3  0xc0567ef5 in mi_switch () at /usr/src/sys/kern/kern_synch.c:470
58:#4  0xc055fa87 in boot (howto=256) at /usr/src/sys/kern/kern_shutdown.c:312
59:#5  0xc056019d in panic () at /usr/src/sys/kern/kern_shutdown.c:550
60:#6  0xc0720c66 in trap_fatal (frame=0xdc1d0b30, eva=0)
61:    at /usr/src/sys/i386/i386/trap.c:821
62:#7  0xc07202b3 in trap (frame=
63:     {tf_fs = -1065484264, tf_es = -1065484272, tf_ds = -1065484272, tf_edi = 1, tf_esi = 0,
```

```
tf_ebp = -602076292, tf_isp = -602076324, tf_ebx = 0, tf_edx = 0, tf_ecx = 1000000, tf_eax =
243, tf_trapno = 12, tf_err = 0, tf_eip = -1066321824, tf_cs = 8, tf_eflags = 65671, tf_esp =
243, tf_ss = 0})
64:    at /usr/src/sys/i386/i386/trap.c:250
65:#8  0xc070c9f8 in calltrap () at {standard input}:94
66:#9  0xc07139f3 in lapic_ipi_vectored (vector=0, dest=0)
67:    at /usr/src/sys/i386/i386/local_apic.c:733
68:#10 0xc0718b23 in ipi_selected (cpus=1, ipi=1)
69:    at /usr/src/sys/i386/i386/mp_machdep.c:1115
70:#11 0xc057473e in kseq_notify (ke=0xcc05e360, cpu=0)
71:    at /usr/src/sys/kern/sched_ule.c:520
72:#12 0xc0575cad in sched_add (td=0xcbcf5c80)
73:    at /usr/src/sys/kern/sched_ule.c:1366
74:#13 0xc05666c6 in setrunqueue (td=0xcc05e360)
75:    at /usr/src/sys/kern/kern_switch.c:422
76:#14 0xc05752f4 in sched_wakeup (td=0xcbcf5c80)
77:    at /usr/src/sys/kern/sched_ule.c:999
78:#15 0xc056816c in setrunnable (td=0xcbcf5c80)
79:    at /usr/src/sys/kern/kern_synch.c:570
80:#16 0xc0567d53 in wakeup (ident=0xcbcf5c80)
81:    at /usr/src/sys/kern/kern_synch.c:411
82:#17 0xc05490a8 in exit1 (td=0xcbcf5b40, rv=0)
83:    at /usr/src/sys/kern/kern_exit.c:509
84:#18 0xc0548011 in sys_exit () at /usr/src/sys/kern/kern_exit.c:102
85:#19 0xc0720fd0 in syscall (frame=
86:     {tf_fs = 47, tf_es = 47, tf_ds = 47, tf_edi = 0, tf_esi = -1, tf_ebp = -1077940712, tf_isp =
-602075788, tf_ebx = 672411944, tf_edx = 10, tf_ecx = 672411600, tf_eax = 1, tf_trapno = 12,
tf_err = 2, tf_eip = 671899563, tf_cs = 31, tf_eflags = 642, tf_esp = -1077940740, tf_ss = 47})
87:    at /usr/src/sys/i386/i386/trap.c:1010
88:#20 0xc070ca4d in Xint0x80_syscall () at {standard input}:136
89:---Can't read userspace from dump, or kernel process---
90:(kgdb) quit
```

If your system is crashing regularly and you are running out of disk space, deleting old vmcore files in /var/crash could save a considerable amount of disk space!

10.3. On-Line Kernel Debugging Using DDB

While kgdb as an off-line debugger provides a very high level of user interface, there are some things it cannot do. The most important ones being breakpointing and single-stepping kernel code.

If you need to do low-level debugging on your kernel, there is an on-line debugger available called DDB. It allows setting of breakpoints, single-stepping kernel functions, examining and changing kernel variables, etc. However, it cannot access kernel source files, and only has access to the global and static symbols, not to the full debug information like kgdb does.

To configure your kernel to include DDB, add the options

```
options KDB
```

```
options DDB
```

to your config file, and rebuild. (See The FreeBSD Handbook for details on configuring the FreeBSD kernel).

Once your DDB kernel is running, there are several ways to enter DDB. The first, and earliest way is to use the boot flag -d. The kernel will start up in debug mode and enter DDB prior to any device probing. Hence you can even debug the device probe/attach functions. To use this, exit the loader's boot menu and enter boot -d at the loader prompt.

The second scenario is to drop to the debugger once the system has booted. There are two simple ways to accomplish this. If you would like to break to the debugger from the command prompt, simply type the command:

```
# sysctl debug.kdb.enter=1
```

Alternatively, if you are at the system console, you may use a hot-key on the keyboard. The default break-to-debugger sequence is Ctrl + Alt + ESC. For syscons, this sequence can be remapped and some of the distributed maps out there do this, so check to make sure you know the right sequence to use. There is an option available for serial consoles that allows the use of a serial line BREAK on the console line to enter DDB (options BREAK_TO_DEBUGGER in the kernel config file). It is not the default since there are a lot of serial adapters around that gratuitously generate a BREAK condition, for example when pulling the cable.

The third way is that any panic condition will branch to DDB if the kernel is configured to use it. For this reason, it is not wise to configure a kernel with DDB for a machine running unattended.

To obtain the unattended functionality, add:

```
options KDB_UNATTENDED
```

to the kernel configuration file and rebuild/reinstall.

The DDB commands roughly resemble some gdb commands. The first thing you probably need to do is to set a breakpoint:

```
break function-name address
```

Numbers are taken hexadecimal by default, but to make them distinct from symbol names; hexadecimal numbers starting with the letters a-f need to be preceded with 0x (this is optional for other numbers). Simple expressions are allowed, for example: function-name + 0x103.

To exit the debugger and continue execution, type:

```
continue
```

To get a stack trace of the current thread, use:

```
trace
```

To get a stack trace of an arbitrary thread, specify a process ID or thread ID as a second argument to trace.

If you want to remove a breakpoint, use

```
del
del address-expression
```

The first form will be accepted immediately after a breakpoint hit, and deletes the current breakpoint. The second form can remove any breakpoint, but you need to specify the exact address; this can be obtained from:

```
show b
```

or:

```
show break
```

To single-step the kernel, try:

```
s
```

This will step into functions, but you can make DDB trace them until the matching return statement is reached by:

```
n
```

This is different from gdb's next statement; it is like gdb's finish. Pressing `n` more than once will cause a continue.

To examine data from memory, use (for example):

```
x/wx 0xf0133fe0,40
x/hd db_symtab_space
x/bc termbuf,10
x/s stringbuf
```

for word/halfword/byte access, and hexadecimal/decimal/character/ string display. The number after the comma is the object count. To display the next 0x10 items, simply use:

```
x ,10
```

Similarly, use

```
x/ia foofunc,10
```

to disassemble the first 0x10 instructions of foofunc, and display them along with their offset from the beginning of foofunc.

To modify memory, use the write command:

```
w/b termbuf 0xa 0xb 0
w/w 0xf0010030 0 0
```

The command modifier (b/h/w) specifies the size of the data to be written, the first following expression is the address to write to and the remainder is interpreted as data to write to successive memory locations.

If you need to know the current registers, use:

```
show reg
```

Alternatively, you can display a single register value by e.g.

```
p $eax
```

and modify it by:

```
set $eax new-value
```

Should you need to call some kernel functions from DDB, simply say:

```
call func(arg1, arg2, ...)
```

The return value will be printed.

For a ps(1) style summary of all running processes, use:

```
ps
```

Now you have examined why your kernel failed, and you wish to reboot. Remember that, depending on the severity of previous malfunctioning, not all parts of the kernel might still be working as expected. Perform one of the following actions to shut down and reboot your system:

```
panic
```

This will cause your kernel to dump core and reboot, so you can later analyze the core on a higher level with kgdb(1).

```
call boot(0)
```

Might be a good way to cleanly shut down the running system, sync() all disks, and finally, in some cases, reboot. As long as the disk and filesystem interfaces of the kernel are not damaged, this could be a good way for an almost clean shutdown.

```
reset
```

This is the final way out of disaster and almost the same as hitting the Big Red Button.

If you need a short command summary, simply type:

```
help
```

It is highly recommended to have a printed copy of the ddb(4) manual page ready for a debugging session. Remember that it is hard to read the on-line manual while single-stepping the kernel.

10.4. On-Line Kernel Debugging Using Remote GDB

This feature has been supported since FreeBSD 2.2, and it is actually a very neat one.

GDB has already supported remote debugging for a long time. This is done using a very simple protocol along a serial line. Unlike the other methods described above, you will need two machines for doing this. One is the host providing the debugging environment, including all the sources, and a copy of the kernel binary with all the symbols in it, and the other one is the target machine that simply runs a similar copy of the very same kernel (but stripped of the debugging information).

You should configure the kernel in question with config -g if building the "traditional" way. If building the "new" way, make sure that makeoptions DEBUG=-g is in the configuration. In both cases, include DDB in the configuration, and compile it as usual. This gives a large binary, due to the debugging information. Copy this kernel to the target machine, strip the debugging symbols off with strip -x, and boot it using the -d boot option. Connect the serial line of the target machine that has "flags 080" set on its uart device to any serial line of the debugging host. See uart(4) for information on how to set the flags on an uart device. Now, on the debugging machine, go to the compile directory of the target kernel, and start gdb:

```
% kgdb kernel
GDB is free software and you are welcome to distribute copies of it
 under certain conditions; type "show copying" to see the conditions.
There is absolutely no warranty for GDB; type "show warranty" for details.
GDB 4.16 (i386-unknown-freebsd),
Copyright 1996 Free Software Foundation, Inc...
(kgdb)
```

Initialize the remote debugging session (assuming the first serial port is being used) by:

```
(kgdb) target remote /dev/cuau0
```

Now, on the target host (the one that entered DDB right before even starting the device probe),

type:

```
Debugger("Boot flags requested debugger")
Stopped at Debugger+0x35: movb  $0, edata+0x51bc
db> gdb
```

DDB will respond with:

```
Next trap will enter GDB remote protocol mode
```

Every time you type gdb, the mode will be toggled between remote GDB and local DDB. In order to force a next trap immediately, simply type s (step). Your hosting GDB will now gain control over the target kernel:

```
Remote debugging using /dev/cuau0
Debugger (msg=0xf01b0383 "Boot flags requested debugger")
   at ../../i386/i386/db_interface.c:257
(kgdb)
```

You can use this session almost as any other GDB session, including full access to the source, running it in gud-mode inside an Emacs window (which gives you an automatic source code display in another Emacs window), etc.

10.5. Debugging a Console Driver

Since you need a console driver to run DDB on, things are more complicated if the console driver itself is failing. You might remember the use of a serial console (either with modified boot blocks, or by specifying -h at the Boot: prompt), and hook up a standard terminal onto your first serial port. DDB works on any configured console driver, including a serial console.

10.6. Debugging Deadlocks

You may experience so called deadlocks, a situation where a system stops doing useful work. To provide a helpful bug report in this situation, use ddb(4) as described in the previous section. Include the output of ps and trace for suspected processes in the report.

If possible, consider doing further investigation. The recipe below is especially useful if you suspect that a deadlock occurs in the VFS layer. Add these options to the kernel configuration file.

```
makeoptions    DEBUG=-g
options    INVARIANTS
options    INVARIANT_SUPPORT
options    WITNESS
options    WITNESS_SKIPSPIN
options    DEBUG_LOCKS
options    DEBUG_VFS_LOCKS
options    DIAGNOSTIC
```

When a deadlock occurs, in addition to the output of the ps command, provide information from the show pcpu, show allpcpu, show locks, show alllocks, show lockedvnods and alltrace.

To obtain meaningful backtraces for threaded processes, use thread thread-id to switch to the thread stack, and do a backtrace with where.

10.7. Kernel debugging with Dcons

dcons(4) is a very simple console driver that is not directly connected with any physical devices. It just reads and writes characters from and to a buffer in a kernel or loader. Due to its simple nature, it is very useful for kernel debugging, especially with a FireWire® device. Currently, FreeBSD provides two ways to interact with the buffer from outside of the kernel using dconschat(8).

10.7.1. Dcons over FireWire®

Most FireWire® (IEEE1394) host controllers are based on the OHCI specification that supports physical access to the host memory. This means that once the host controller is initialized, we can access the host memory without the help of software (kernel). We can exploit this facility for interaction with dcons(4). dcons(4) provides similar functionality as a serial console. It emulates two serial ports, one for the console and DDB, the other for GDB. Because remote memory access is fully handled by the hardware, the dcons(4) buffer is accessible even when the system crashes.

FireWire® devices are not limited to those integrated into motherboards. PCI cards exist for desktops, and a cardbus interface can be purchased for laptops.

10.7.1.1. Enabling FireWire® and Dcons support on the target machine

To enable FireWire® and Dcons support in the kernel of the target machine:

- Make sure your kernel supports dcons, dcons_crom and firewire. Dcons should be statically linked with the kernel. For dcons_crom and firewire, modules should be OK.
- Make sure physical DMA is enabled. You may need to add hw.firewire.phydma_enable=1 to /boot/loader.conf.
- Add options for debugging.
- Add dcons_gdb=1 in /boot/loader.conf if you use GDB over FireWire®.
- Enable dcons in /etc/ttys.
- Optionally, to force dcons to be the high-level console, add hw.firewire.dcons_crom.force_console=1 to loader.conf.

To enable FireWire® and Dcons support in loader(8) on i386 or amd64:

Add LOADER_FIREWIRE_SUPPORT=YES in /etc/make.conf and rebuild loader(8):

```
# cd /sys/boot/i386 && make clean && make && make install
```

To enable dcons(4) as an active low-level console, add boot_multicons="YES" to /boot/loader.conf.

Here are a few configuration examples. A sample kernel configuration file would contain:

```
device dcons
device dcons_crom
options KDB
options DDB
options GDB
```

```
options ALT_BREAK_TO_DEBUGGER
```

And a sample /boot/loader.conf would contain:

```
dcons_crom_load="YES"
dcons_gdb=1
boot_multicons="YES"
hw.firewire.phydma_enable=1
hw.firewire.dcons_crom.force_console=1
```

10.7.1.2. Enabling FireWire® and Dcons support on the host machine

To enable FireWire® support in the kernel on the host machine:

```
# kldload firewire
```

Find out the EUI64 (the unique 64 bit identifier) of the FireWire® host controller, and use fwcontrol(8) or dmesg to find the EUI64 of the target machine.

Run dconschat(8), with:

```
# dconschat -e \# -br -G 12345 -t 00-11-22-33-44-55-66-77
```

The following key combinations can be used once dconschat(8) is running:

~ + .	Disconnect
~	ALT BREAK
~	RESET target
~	Suspend dconschat

Attach remote GDB by starting kgdb(1) with a remote debugging session:

```
kgdb -r :12345 kernel
```

10.7.1.3. Some general tips

Here are some general tips:

To take full advantage of the speed of FireWire®, disable other slow console drivers:

```
# conscontrol delete ttyd0     # serial console
# conscontrol delete consolectl # video/keyboard
```

There exists a GDB mode for emacs(1); this is what you will need to add to your .emacs:

```
(setq gud-gdba-command-name "kgdb -a -a -a -r :12345")
```

```
(setq gdb-many-windows t)
(xterm-mouse-mode 1)
M-x gdba
```

And for DDD (devel/ddd):

```
# remote serial protocol
LANG=C ddd --debugger kgdb -r :12345 kernel
# live core debug
LANG=C ddd --debugger kgdb kernel /dev/fwmem0.2
```

10.7.2. Dcons with KVM

We can directly read the dcons(4) buffer via /dev/mem for live systems, and in the core dump for crashed systems. These give you similar output to dmesg -a, but the dcons(4) buffer includes more information.

10.7.2.1. Using Dcons with KVM

To use dcons(4) with KVM:

Dump a dcons(4) buffer of a live system:

```
# dconschat -1
```

Dump a dcons(4) buffer of a crash dump:

```
# dconschat -1 -M vmcore.XX
```

Live core debugging can be done via:

```
# fwcontrol -m target_eui64
# kgdb kernel /dev/fwmem0.2
```

10.8. Glossary of Kernel Options for Debugging

This section provides a brief glossary of compile-time kernel options used for debugging:

- options KDB: compiles in the kernel debugger framework. Required for options DDB and options GDB. Little or no performance overhead. By default, the debugger will be entered on panic instead of an automatic reboot.
- options KDB_UNATTENDED: change the default value of the debug.debugger_on_panic sysctl to 0, which controls whether the debugger is entered on panic. When options KDB is not compiled into the kernel, the behavior is to automatically reboot on panic; when it is compiled into the kernel, the default behavior is to drop into the debugger unless options KDB_UNATTENDED is compiled in. If you want to leave the kernel debugger compiled into the kernel but want the system to come back up unless you’ re on-hand to use the debugger for diagnostics, use this option.
- options KDB_TRACE: change the default value of the debug.trace_on_panic sysctl to 1, which

controls whether the debugger automatically prints a stack trace on panic. Especially if running with options KDB_UNATTENDED, this can be helpful to gather basic debugging information on the serial or firewire console while still rebooting to recover.

- options DDB: compile in support for the console debugger, DDB. This interactive debugger runs on whatever the active low-level console of the system is, which includes the video console, serial console, or firewire console. It provides basic integrated debugging facilities, such as stack tracing, process and thread listing, dumping of lock state, VM state, file system state, and kernel memory management. DDB does not require software running on a second machine or being able to generate a core dump or full debugging kernel symbols, and provides detailed diagnostics of the kernel at run-time. Many bugs can be fully diagnosed using only DDB output. This option depends on options KDB.
- options GDB: compile in support for the remote debugger, GDB, which can operate over serial cable or firewire. When the debugger is entered, GDB may be attached to inspect structure contents, generate stack traces, etc. Some kernel state is more awkward to access than in DDB, which is able to generate useful summaries of kernel state automatically, such as automatically walking lock debugging or kernel memory management structures, and a second machine running the debugger is required. On the other hand, GDB combines information from the kernel source and full debugging symbols, and is aware of full data structure definitions, local variables, and is scriptable. This option is not required to run GDB on a kernel core dump. This option depends on options KDB.
- options BREAK_TO_DEBUGGER, options ALT_BREAK_TO_DEBUGGER: allow a break signal or alternative signal on the console to enter the debugger. If the system hangs without a panic, this is a useful way to reach the debugger. Due to the current kernel locking, a break signal generated on a serial console is significantly more reliable at getting into the debugger, and is generally recommended. This option has little or no performance impact.
- options INVARIANTS: compile into the kernel a large number of run-time assertion checks and tests, which constantly test the integrity of kernel data structures and the invariants of kernel algorithms. These tests can be expensive, so are not compiled in by default, but help provide useful "fail stop" behavior, in which certain classes of undesired behavior enter the debugger before kernel data corruption occurs, making them easier to debug. Tests include memory scrubbing and use-after-free testing, which is one of the more significant sources of overhead. This option depends on options INVARIANT_SUPPORT.
- options INVARIANT_SUPPORT: many of the tests present in options INVARIANTS require modified data structures or additional kernel symbols to be defined.
- options WITNESS: this option enables run-time lock order tracking and verification, and is an invaluable tool for deadlock diagnosis. WITNESS maintains a graph of acquired lock orders by lock type, and checks the graph at each acquire for cycles (implicit or explicit). If a cycle is detected, a warning and stack trace are generated to the console, indicating that a potential deadlock might have occurred. WITNESS is required in order to use the show locks, show witness and show alllocks DDB commands. This debug option has significant performance overhead, which may be somewhat mitigated through the use of options WITNESS_SKIPSPIN. Detailed documentation may be found in witness(4).
- options WITNESS_SKIPSPIN: disable run-time checking of spinlock lock order with WITNESS. As spin locks are acquired most frequently in the scheduler, and scheduler events occur often, this option can significantly speed up systems running with WITNESS. This option depends on options WITNESS.
- options WITNESS_KDB: change the default value of the debug.witness.kdb sysctl to 1, which causes WITNESS to enter the debugger when a lock order violation is detected, rather than simply printing a warning. This option depends on options WITNESS.
- options SOCKBUF_DEBUG: perform extensive run-time consistency checking on socket buffers, which can be useful for debugging both socket bugs and race conditions in protocols and device drivers that interact with sockets. This option significantly impacts network performance, and may change the timing in device driver races.
- options DEBUG_VFS_LOCKS: track lock acquisition points for lockmgr/vnode locks, expanding the amount of information displayed by show lockedvnods in DDB. This option has a measurable performance impact.
- options DEBUG_MEMGUARD: a replacement for the malloc(9) kernel memory allocator that uses

the VM system to detect reads or writes from allocated memory after free. Details may be found in memguard(9). This option has a significant performance impact, but can be very helpful in debugging kernel memory corruption bugs.

- options DIAGNOSTIC: enable additional, more expensive diagnostic tests along the lines of options INVARIANTS.

Part IV: Architectures(電腦架構)

Chapter 11. x86 Assembly Language Programming

This chapter was written by G. Adam Stanislav <adam@redprince.net>.

11.1. Synopsis

Assembly language programming under UNIX® is highly undocumented. It is generally assumed that no one would ever want to use it because various UNIX® systems run on different microprocessors, so everything should be written in C for portability.

In reality, C portability is quite a myth. Even C programs need to be modified when ported from one UNIX® to another, regardless of what processor each runs on. Typically, such a program is full of conditional statements depending on the system it is compiled for.

Even if we believe that all of UNIX® software should be written in C, or some other high-level language, we still need assembly language programmers: Who else would write the section of C library that accesses the kernel?

In this chapter I will attempt to show you how you can use assembly language writing UNIX® programs, specifically under FreeBSD.

This chapter does not explain the basics of assembly language. There are enough resources about that (for a complete online course in assembly language, see Randall Hyde's Art of Assembly Language; or if you prefer a printed book, take a look at Jeff Duntemann's Assembly Language Step-by-Step (ISBN: 0471375233). However, once the chapter is finished, any assembly language programmer will be able to write programs for FreeBSD quickly and efficiently.

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11.2. The Tools

11.2.1. The Assembler

The most important tool for assembly language programming is the assembler, the software that converts assembly language code into machine language.

Two very different assemblers are available for FreeBSD. One is as(1), which uses the traditional UNIX® assembly language syntax. It comes with the system.

The other is /usr/ports/devel/nasm. It uses the Intel syntax. Its main advantage is that it can assemble code for many operating systems. It needs to be installed separately, but is completely free.

This chapter uses nasm syntax because most assembly language programmers coming to FreeBSD from other operating systems will find it easier to understand. And, because, quite frankly, that is what I am used to.

11.2.2. The Linker

The output of the assembler, like that of any compiler, needs to be linked to form an executable file.

The standard ld(1) linker comes with FreeBSD. It works with the code assembled with either assembler.

11.3. System Calls

11.3.1. Default Calling Convention

By default, the FreeBSD kernel uses the C calling convention. Further, although the kernel is accessed using int 80h, it is assumed the program will call a function that issues int 80h, rather than issuing int 80h directly.

This convention is very convenient, and quite superior to the Microsoft® convention used by MS-DOS®. Why? Because the UNIX® convention allows any program written in any language to access the kernel.

An assembly language program can do that as well. For example, we could open a file:

```
kernel:
   int 80h ; Call kernel
   ret

open:
   push   dword mode
   push   dword flags
   push   dword path
   mov eax, 5
   call   kernel
   add esp, byte 12
   ret
```

This is a very clean and portable way of coding. If you need to port the code to a UNIX® system which uses a different interrupt, or a different way of passing parameters, all you need to change is the kernel procedure.

But assembly language programmers like to shave off cycles. The above example requires a call/ret combination. We can eliminate it by pushing an extra dword:

```
open:
   push   dword mode
   push   dword flags
   push   dword path
   mov eax, 5
   push   eax    ; Or any other dword
   int 80h
   add esp, byte 16
```

The 5 that we have placed in EAX identifies the kernel function, in this case open.

11.3.2. Alternate Calling Convention

FreeBSD is an extremely flexible system. It offers other ways of calling the kernel. For it to work, however, the system must have Linux emulation installed.

Linux is a UNIX® like system. However, its kernel uses the same system-call convention of passing parameters in registers MS-DOS® does. As with the UNIX® convention, the function number is placed in EAX. The parameters, however, are not passed on the stack but in EBX, ECX, EDX, ESI, EDI, EBP:

```
open:
   mov eax, 5
   mov ebx, path
   mov ecx, flags
   mov edx, mode
   int 80h
```

This convention has a great disadvantage over the UNIX® way, at least as far as assembly language programming is concerned: Every time you make a kernel call you must push the registers, then pop them later. This makes your code bulkier and slower. Nevertheless, FreeBSD gives you a choice.

If you do choose the Linux convention, you must let the system know about it. After your program is assembled and linked, you need to brand the executable:

```
% brandelf -t Linux filename
```

11.3.3. Which Convention Should You Use?

If you are coding specifically for FreeBSD, you should always use the UNIX® convention: It is faster, you can store global variables in registers, you do not have to brand the executable, and you do not impose the installation of the Linux emulation package on the target system.

If you want to create portable code that can also run on Linux, you will probably still want to give the FreeBSD users as efficient a code as possible. I will show you how you can accomplish that after I have explained the basics.

11.3.4. Call Numbers

To tell the kernel which system service you are calling, place its number in EAX. Of course, you need to know what the number is.

11.3.4.1. The syscalls File

The numbers are listed in syscalls. locate syscalls finds this file in several different formats, all produced automatically from syscalls.master.

You can find the master file for the default UNIX® calling convention in /usr/src/sys/kern/syscalls.master. If you need to use the other convention implemented in the Linux emulation mode, read /usr/src/sys/i386/linux/syscalls.master.

Not only do FreeBSD and Linux use different calling conventions, they sometimes use different numbers for the same functions.

syscalls.master describes how the call is to be made:

```
0  STD NOHIDE  { int nosys(void); } syscall nosys_args int
1  STD NOHIDE  { void exit(int rval); } exit rexit_args void
2  STD POSIX   { int fork(void); }
```

```
3  STD POSIX  { ssize_t read(int fd, void *buf, size_t nbyte); }
4  STD POSIX  { ssize_t write(int fd, const void *buf, size_t nbyte); }
5  STD POSIX  { int open(char *path, int flags, int mode); }
6  STD POSIX  { int close(int fd); }
etc...
```

It is the leftmost column that tells us the number to place in EAX.

The rightmost column tells us what parameters to push. They are pushed from right to left.

For example, to open a file, we need to push the mode first, then flags, then the address at which the path is stored.

11.4. Return Values

A system call would not be useful most of the time if it did not return some kind of a value: The file descriptor of an open file, the number of bytes read to a buffer, the system time, etc.

Additionally, the system needs to inform us if an error occurs: A file does not exist, system resources are exhausted, we passed an invalid parameter, etc.

11.4.1. Man Pages

The traditional place to look for information about various system calls under UNIX® systems are the manual pages. FreeBSD describes its system calls in section 2, sometimes in section 3.

For example, open(2) says:

If successful, open() returns a non-negative integer, termed a file descriptor. It returns -1 on failure, and sets errno to indicate the error.

The assembly language programmer new to UNIX® and FreeBSD will immediately ask the puzzling question: Where is errno and how do I get to it?

The information presented in the manual pages applies to C programs. The assembly language programmer needs additional information.

11.4.2. Where Are the Return Values?

Unfortunately, it depends··· For most system calls it is in EAX, but not for all. A good rule of thumb, when working with a system call for the first time, is to look for the return value in EAX. If it is not there, you need further research.

I am aware of one system call that returns the value in EDX: SYS_fork. All others I have worked with use EAX. But I have not worked with them all yet.

If you cannot find the answer here or anywhere else, study libc source code and see how it interfaces with the kernel.

11.4.3. Where Is errno?

Actually, nowhere···

errno is part of the C language, not the UNIX® kernel. When accessing kernel services directly, the error code is returned in EAX, the same register the proper return value generally ends up in.

This makes perfect sense. If there is no error, there is no error code. If there is an error, there is no return value. One register can contain either.

11.4.4. Determining an Error Occurred

When using the standard FreeBSD calling convention, the carry flag is cleared upon success, set upon failure.

When using the Linux emulation mode, the signed value in EAX is non-negative upon success, and contains the return value. In case of an error, the value is negative, i.e., -errno.

11.5. Creating Portable Code

Portability is generally not one of the strengths of assembly language. Yet, writing assembly language programs for different platforms is possible, especially with nasm. I have written assembly language libraries that can be assembled for such different operating systems as Windows® and FreeBSD.

It is all the more possible when you want your code to run on two platforms which, while different, are based on similar architectures.

For example, FreeBSD is UNIX®, Linux is UNIX® like. I only mentioned three differences between them (from an assembly language programmer's perspective): The calling convention, the function numbers, and the way of returning values.

11.5.1. Dealing with Function Numbers

In many cases the function numbers are the same. However, even when they are not, the problem is easy to deal with: Instead of using numbers in your code, use constants which you have declared differently depending on the target architecture:

```
%ifdef  LINUX
%define SYS_execve  11
%else
%define SYS_execve  59
%endif
```

11.5.2. Dealing with Conventions

Both, the calling convention, and the return value (the errno problem) can be resolved with macros:

```
%ifdef  LINUX

%macro  system  0
  call   kernel
%endmacro

align 4
kernel:
  push   ebx
  push   ecx
```

```
    push   edx
    push   esi
    push   edi
    push   ebp

    mov ebx, [esp+32]
    mov ecx, [esp+36]
    mov edx, [esp+40]
    mov esi, [esp+44]
    mov ebp, [esp+48]
    int 80h

    pop ebp
    pop edi
    pop esi
    pop edx
    pop ecx
    pop ebx

    or  eax, eax
    js  .errno
    clc
    ret

.errno:
    neg eax
    stc
    ret

%else

%macro  system  0
    int 80h
%endmacro

%endif
```

11.5.3. Dealing with Other Portability Issues

The above solutions can handle most cases of writing code portable between FreeBSD and Linux. Nevertheless, with some kernel services the differences are deeper.

In that case, you need to write two different handlers for those particular system calls, and use conditional assembly. Luckily, most of your code does something other than calling the kernel, so usually you will only need a few such conditional sections in your code.

11.5.4. Using a Library

You can avoid portability issues in your main code altogether by writing a library of system calls. Create a separate library for FreeBSD, a different one for Linux, and yet other libraries for more operating systems.

In your library, write a separate function (or procedure, if you prefer the traditional assembly language terminology) for each system call. Use the C calling convention of passing parameters. But still use EAX to pass the call number in. In that case, your FreeBSD library can be very simple, as many seemingly different functions can be just labels to the same code:

```
sys.open:
sys.close:
[etc...]
   int 80h
   ret
```

Your Linux library will require more different functions. But even here you can group system calls using the same number of parameters:

```
sys.exit:
sys.close:
[etc... one-parameter functions]
   push   ebx
   mov ebx, [esp+12]
   int 80h
   pop ebx
   jmp sys.return

...

sys.return:
   or  eax, eax
   js  sys.err
   clc
   ret

sys.err:
   neg eax
   stc
   ret
```

The library approach may seem inconvenient at first because it requires you to produce a separate file your code depends on. But it has many advantages: For one, you only need to write it once and can use it for all your programs. You can even let other assembly language programmers use it, or perhaps use one written by someone else. But perhaps the greatest advantage of the library is that your code can be ported to other systems, even by other programmers, by simply writing a new library without any changes to your code.

If you do not like the idea of having a library, you can at least place all your system calls in a separate assembly language file and link it with your main program. Here, again, all porters have to do is create a new object file to link with your main program.

11.5.5. Using an Include File

If you are releasing your software as (or with) source code, you can use macros and place them in a separate file, which you include in your code.

Porters of your software will simply write a new include file. No library or external object file is necessary, yet your code is portable without any need to edit the code.

This is the approach we will use throughout this chapter. We will name our include file system.inc, and add to it whenever we deal with a new system call.

We can start our system.inc by declaring the standard file descriptors:

```
%define stdin  0
%define stdout 1
%define stderr 2
```

Next, we create a symbolic name for each system call:

```
%define SYS_nosys  0
%define SYS_exit   1
%define SYS_fork   2
%define SYS_read   3
%define SYS_write  4
; [etc...]
```

We add a short, non-global procedure with a long name, so we do not accidentally reuse the name in our code:

```
section .text
align 4
access.the.bsd.kernel:
  int 80h
  ret
```

We create a macro which takes one argument, the syscall number:

```
%macro  system  1
  mov eax, %1
  call   access.the.bsd.kernel
%endmacro
```

Finally, we create macros for each syscall. These macros take no arguments.

```
%macro  sys.exit   0
  system  SYS_exit
%endmacro

%macro  sys.fork   0
  system  SYS_fork
%endmacro

%macro  sys.read   0
  system  SYS_read
%endmacro

%macro  sys.write  0
  system  SYS_write
%endmacro

; [etc...]
```

Go ahead, enter it into your editor and save it as system.inc. We will add more to it as we discuss more syscalls.

11.6. Our First Program

We are now ready for our first program, the mandatory Hello, World!

```
 1:  %include   'system.inc'
 2:
 3: section .data
 4: hello   db  'Hello, World!', 0Ah
 5: hbytes  equ $-hello
 6:
 7: section .text
 8: global  _start
 9: _start:
10: push    dword hbytes
11: push    dword hello
12: push    dword stdout
13: sys.write
14:
15: push    dword 0
16: sys.exit
```

Here is what it does: Line 1 includes the defines, the macros, and the code from system.inc.

Lines 3-5 are the data: Line 3 starts the data section/segment. Line 4 contains the string "Hello, World!" followed by a new line (0Ah). Line 5 creates a constant that contains the length of the string from line 4 in bytes.

Lines 7-16 contain the code. Note that FreeBSD uses the elf file format for its executables, which requires every program to start at the point labeled _start (or, more precisely, the linker expects that). This label has to be global.

Lines 10-13 ask the system to write hbytes bytes of the hello string to stdout.

Lines 15-16 ask the system to end the program with the return value of 0. The SYS_exit syscall never returns, so the code ends there.

If you have come to UNIX® from MS-DOS® assembly language background, you may be used to writing directly to the video hardware. You will never have to worry about this in FreeBSD, or any other flavor of UNIX®. As far as you are concerned, you are writing to a file known as stdout. This can be the video screen, or a telnet terminal, or an actual file, or even the input of another program. Which one it is, is for the system to figure out.

11.6.1. Assembling the Code

Type the code (except the line numbers) in an editor, and save it in a file named hello.asm. You need nasm to assemble it.

11.6.1.1. Installing nasm

If you do not have nasm, type:

```
% su
Password:your root password
# cd /usr/ports/devel/nasm
# make install
# exit
%
```

You may type make install clean instead of just make install if you do not want to keep nasm source code.

Either way, FreeBSD will automatically download nasm from the Internet, compile it, and install it on your system.

If your system is not FreeBSD, you need to get nasm from its home page. You can still use it to assemble FreeBSD code.

Now you can assemble, link, and run the code:

```
% nasm -f elf hello.asm
% ld -s -o hello hello.o
% ./hello
Hello, World!
%
```

11.7. Writing UNIX® Filters

A common type of UNIX® application is a filter-a program that reads data from the stdin, processes it somehow, then writes the result to stdout.

In this chapter, we shall develop a simple filter, and learn how to read from stdin and write to stdout. This filter will convert each byte of its input into a hexadecimal number followed by a blank space.

```
%include   'system.inc'

section .data
hex db  '0123456789ABCDEF'
buffer  db  0, 0, ' '

section .text
global  _start
_start:
   ; read a byte from stdin
   push    dword 1
   push    dword buffer
   push    dword stdin
   sys.read
   add esp, byte 12
   or  eax, eax
   je  .done

   ; convert it to hex
   movzx   eax, byte [buffer]
   mov edx, eax
   shr dl, 4
   mov dl, [hex+edx]
   mov [buffer], dl
   and al, 0Fh
   mov al, [hex+eax]
   mov [buffer+1], al

   ; print it
   push    dword 3
   push    dword buffer
   push    dword stdout
   sys.write
   add esp, byte 12
   jmp short _start
```

```
.done:
   push   dword 0
   sys.exit
```

In the data section we create an array called hex. It contains the 16 hexadecimal digits in ascending order. The array is followed by a buffer which we will use for both input and output. The first two bytes of the buffer are initially set to 0. This is where we will write the two hexadecimal digits (the first byte also is where we will read the input). The third byte is a space.

The code section consists of four parts: Reading the byte, converting it to a hexadecimal number, writing the result, and eventually exiting the program.

To read the byte, we ask the system to read one byte from stdin, and store it in the first byte of the buffer. The system returns the number of bytes read in EAX. This will be 1 while data is coming, or 0, when no more input data is available. Therefore, we check the value of EAX. If it is 0, we jump to .done, otherwise we continue.

For simplicity sake, we are ignoring the possibility of an error condition at this time.

The hexadecimal conversion reads the byte from the buffer into EAX, or actually just AL, while clearing the remaining bits of EAX to zeros. We also copy the byte to EDX because we need to convert the upper four bits (nibble) separately from the lower four bits. We store the result in the first two bytes of the buffer.

Next, we ask the system to write the three bytes of the buffer, i.e., the two hexadecimal digits and the blank space, to stdout. We then jump back to the beginning of the program and process the next byte.

Once there is no more input left, we ask the system to exit our program, returning a zero, which is the traditional value meaning the program was successful.

Go ahead, and save the code in a file named hex.asm, then type the following (the ^D means press the control key and type D while holding the control key down):

```
% nasm -f elf hex.asm
% ld -s -o hex hex.o
% ./hex
Hello, World!
48 65 6C 6C 6F 2C 20 57 6F 72 6C 64 21 0A Here I come!
48 65 72 65 20 49 20 63 6F 6D 65 21 0A ^D %
```

If you are migrating to UNIX® from MS-DOS®, you may be wondering why each line ends with 0A instead of 0D 0A. This is because UNIX® does not use the cr/lf convention, but a "new line" convention, which is 0A in hexadecimal.

Can we improve this? Well, for one, it is a bit confusing because once we have converted a line of text, our input no longer starts at the beginning of the line. We can modify it to print a new line instead of a space after each 0A:

```
%include   'system.inc'
```

```
section .data
hex db  '0123456789ABCDEF'
buffer  db  0, 0, ' '

section .text
global  _start
_start:
   mov cl, ' '

.loop:
   ; read a byte from stdin
   push   dword 1
   push   dword buffer
   push   dword stdin
   sys.read
   add esp, byte 12
   or  eax, eax
   je  .done

   ; convert it to hex
   movzx   eax, byte [buffer]
   mov [buffer+2], cl
   cmp al, 0Ah
   jne .hex
   mov [buffer+2], al

.hex:
   mov edx, eax
   shr dl, 4
   mov dl, [hex+edx]
   mov [buffer], dl
   and al, 0Fh
   mov al, [hex+eax]
   mov [buffer+1], al

   ; print it
   push   dword 3
   push   dword buffer
   push   dword stdout
   sys.write
   add esp, byte 12
   jmp short .loop
```

```
.done:
   push   dword 0
   sys.exit
```

We have stored the space in the CL register. We can do this safely because, unlike Microsoft® Windows®, UNIX® system calls do not modify the value of any register they do not use to return a value in.

That means we only need to set CL once. We have, therefore, added a new label .loop and jump to it for the next byte instead of jumping at _start. We have also added the .hex label so we can either have a blank space or a new line as the third byte of the buffer.

Once you have changed hex.asm to reflect these changes, type:

```
% nasm -f elf hex.asm
% ld -s -o hex hex.o
% ./hex
Hello, World!
48 65 6C 6C 6F 2C 20 57 6F 72 6C 64 21 0A
Here I come!
48 65 72 65 20 49 20 63 6F 6D 65 21 0A
^D %
```

That looks better. But this code is quite inefficient! We are making a system call for every single byte twice (once to read it, another time to write the output).

11.8. Buffered Input and Output

We can improve the efficiency of our code by buffering our input and output. We create an input buffer and read a whole sequence of bytes at one time. Then we fetch them one by one from the buffer.

We also create an output buffer. We store our output in it until it is full. At that time we ask the kernel to write the contents of the buffer to stdout.

The program ends when there is no more input. But we still need to ask the kernel to write the contents of our output buffer to stdout one last time, otherwise some of our output would make it to the output buffer, but never be sent out. Do not forget that, or you will be wondering why some of your output is missing.

```
%include   'system.inc'

%define BUFSIZE 2048

section .data
hex db  '0123456789ABCDEF'

section .bss
```

```
ibuffer resb    BUFSIZE
obuffer resb    BUFSIZE

section .text
global  _start
_start:
    sub eax, eax
    sub ebx, ebx
    sub ecx, ecx
    mov edi, obuffer

.loop:
    ; read a byte from stdin
    call    getchar

    ; convert it to hex
    mov dl, al
    shr al, 4
    mov al, [hex+eax]
    call    putchar

    mov al, dl
    and al, 0Fh
    mov al, [hex+eax]
    call    putchar

    mov al, ' '
    cmp dl, 0Ah
    jne .put
    mov al, dl

.put:
    call    putchar
    jmp short .loop

align 4
getchar:
    or  ebx, ebx
    jne .fetch

    call    read
```

```
.fetch:
   lodsb
   dec ebx
   ret

read:
   push   dword BUFSIZE
   mov esi, ibuffer
   push   esi
   push   dword stdin
   sys.read
   add esp, byte 12
   mov ebx, eax
   or  eax, eax
   je  .done
   sub eax, eax
   ret

align 4
.done:
   call   write     ; flush output buffer
   push   dword 0
   sys.exit

align 4
putchar:
   stosb
   inc ecx
   cmp ecx, BUFSIZE
   je  write
   ret

align 4
write:
   sub edi, ecx   ; start of buffer
   push   ecx
   push   edi
   push   dword stdout
   sys.write
   add esp, byte 12
   sub eax, eax
   sub ecx, ecx   ; buffer is empty now
```

```
    ret
```

We now have a third section in the source code, named .bss. This section is not included in our executable file, and, therefore, cannot be initialized. We use resb instead of db. It simply reserves the requested size of uninitialized memory for our use.

We take advantage of the fact that the system does not modify the registers: We use registers for what, otherwise, would have to be global variables stored in the .data section. This is also why the UNIX® convention of passing parameters to system calls on the stack is superior to the Microsoft convention of passing them in the registers: We can keep the registers for our own use.

We use EDI and ESI as pointers to the next byte to be read from or written to. We use EBX and ECX to keep count of the number of bytes in the two buffers, so we know when to dump the output to, or read more input from, the system.

Let us see how it works now:

```
% nasm -f elf hex.asm
% ld -s -o hex hex.o
% ./hex
Hello, World!
Here I come!
48 65 6C 6C 6F 2C 20 57 6F 72 6C 64 21 0A
48 65 72 65 20 49 20 63 6F 6D 65 21 0A
^D %
```

Not what you expected? The program did not print the output until we pressed ^D. That is easy to fix by inserting three lines of code to write the output every time we have converted a new line to 0A. I have marked the three lines with > (do not copy the > in your hex.asm).

```
%include    'system.inc'

%define BUFSIZE 2048

section .data
hex db  '0123456789ABCDEF'

section .bss
ibuffer resb    BUFSIZE
obuffer resb    BUFSIZE

section .text
global  _start
_start:
    sub eax, eax
    sub ebx, ebx
    sub ecx, ecx
```

```
    mov edi, obuffer

.loop:
    ; read a byte from stdin
    call    getchar

    ; convert it to hex
    mov dl, al
    shr al, 4
    mov al, [hex+eax]
    call    putchar

    mov al, dl
    and al, 0Fh
    mov al, [hex+eax]
    call    putchar

    mov al, ' '
    cmp dl, 0Ah
    jne .put
    mov al, dl

.put:
    call    putchar
>   cmp al, 0Ah
>   jne .loop
>   call    write
    jmp short .loop

align 4
getchar:
    or  ebx, ebx
    jne .fetch

    call    read

.fetch:
    lodsb
    dec ebx
    ret

read:
```

```
    push    dword BUFSIZE
    mov esi, ibuffer
    push    esi
    push    dword stdin
    sys.read
    add esp, byte 12
    mov ebx, eax
    or  eax, eax
    je  .done
    sub eax, eax
    ret

align 4
.done:
    call    write       ; flush output buffer
    push    dword 0
    sys.exit

align 4
putchar:
    stosb
    inc ecx
    cmp ecx, BUFSIZE
    je  write
    ret

align 4
write:
    sub edi, ecx    ; start of buffer
    push    ecx
    push    edi
    push    dword stdout
    sys.write
    add esp, byte 12
    sub eax, eax
    sub ecx, ecx    ; buffer is empty now
    ret
```

Now, let us see how it works:

```
% nasm -f elf hex.asm
% ld -s -o hex hex.o
```

```
% ./hex
Hello, World!
48 65 6C 6C 6F 2C 20 57 6F 72 6C 64 21 0A
Here I come!
48 65 72 65 20 49 20 63 6F 6D 65 21 0A
^D %
```

Not bad for a 644-byte executable, is it!

This approach to buffered input/output still contains a hidden danger. I will discuss-and fix-it later, when I talk about the dark side of buffering.

11.8.1. How to Unread a Character

This may be a somewhat advanced topic, mostly of interest to programmers familiar with the theory of compilers. If you wish, you may skip to the next section, and perhaps read this later.

While our sample program does not require it, more sophisticated filters often need to look ahead. In other words, they may need to see what the next character is (or even several characters). If the next character is of a certain value, it is part of the token currently being processed. Otherwise, it is not.

For example, you may be parsing the input stream for a textual string (e.g., when implementing a language compiler): If a character is followed by another character, or perhaps a digit, it is part of the token you are processing. If it is followed by white space, or some other value, then it is not part of the current token.

This presents an interesting problem: How to return the next character back to the input stream, so it can be read again later?

One possible solution is to store it in a character variable, then set a flag. We can modify getchar to check the flag, and if it is set, fetch the byte from that variable instead of the input buffer, and reset the flag. But, of course, that slows us down.

The C language has an ungetc() function, just for that purpose. Is there a quick way to implement it in our code? I would like you to scroll back up and take a look at the getchar procedure and see if you can find a nice and fast solution before reading the next paragraph. Then come back here and see my own solution.

The key to returning a character back to the stream is in how we are getting the characters to start with:

First we check if the buffer is empty by testing the value of EBX. If it is zero, we call the read procedure.

If we do have a character available, we use lodsb, then decrease the value of EBX. The lodsb instruction is effectively identical to:

```
mov al, [esi]
  inc esi
```

The byte we have fetched remains in the buffer until the next time read is called. We do not know when that happens, but we do know it will not happen until the next call to getchar. Hence, to "return" the last-read byte back to the stream, all we have to do is decrease the value of ESI and

increase the value of EBX:

```
ungetc:
   dec esi
   inc ebx
   ret
```

But, be careful! We are perfectly safe doing this if our look-ahead is at most one character at a time. If we are examining more than one upcoming character and call ungetc several times in a row, it will work most of the time, but not all the time (and will be tough to debug). Why?

Because as long as getchar does not have to call read, all of the pre-read bytes are still in the buffer, and our ungetc works without a glitch. But the moment getchar calls read, the contents of the buffer change.

We can always rely on ungetc working properly on the last character we have read with getchar, but not on anything we have read before that.

If your program reads more than one byte ahead, you have at least two choices:

If possible, modify the program so it only reads one byte ahead. This is the simplest solution.

If that option is not available, first of all determine the maximum number of characters your program needs to return to the input stream at one time. Increase that number slightly, just to be sure, preferably to a multiple of 16-so it aligns nicely. Then modify the .bss section of your code, and create a small "spare" buffer right before your input buffer, something like this:

```
section .bss
   resb   16  ; or whatever the value you came up with
ibuffer resb   BUFSIZE
obuffer resb   BUFSIZE
```

You also need to modify your ungetc to pass the value of the byte to unget in AL:

```
ungetc:
   dec esi
   inc ebx
   mov [esi], al
   ret
```

With this modification, you can call ungetc up to 17 times in a row safely (the first call will still be within the buffer, the remaining 16 may be either within the buffer or within the "spare").

11.9. Command Line Arguments

Our hex program will be more useful if it can read the names of an input and output file from its command line, i.e., if it can process the command line arguments. But··· Where are they?

Before a UNIX® system starts a program, it pushes some data on the stack, then jumps at the _start label of the program. Yes, I said jumps, not calls. That means the data can be accessed by reading [esp+offset], or by simply popping it.

The value at the top of the stack contains the number of command line arguments. It is traditionally called argc, for "argument count."

Command line arguments follow next, all argc of them. These are typically referred to as argv, for "argument value(s)." That is, we get argv[0], argv[1], ⋯, argv[argc-1]. These are not the actual arguments, but pointers to arguments, i.e., memory addresses of the actual arguments. The arguments themselves are NUL-terminated character strings.

The argv list is followed by a NULL pointer, which is simply a 0. There is more, but this is enough for our purposes right now.

If you have come from the MS-DOS® programming environment, the main difference is that each argument is in a separate string. The second difference is that there is no practical limit on how many arguments there can be.

Armed with this knowledge, we are almost ready for the next version of hex.asm. First, however, we need to add a few lines to system.inc:

First, we need to add two new entries to our list of system call numbers:

```
%define SYS_open   5
%define SYS_close  6
```

Then we add two new macros at the end of the file:

```
%macro  sys.open   0
  system  SYS_open
%endmacro

%macro  sys.close  0
  system  SYS_close
%endmacro
```

Here, then, is our modified source code:

```
%include   'system.inc'

%define BUFSIZE 2048

section .data
fd.in   dd  stdin
fd.out  dd  stdout
hex db  '0123456789ABCDEF'

section .bss
ibuffer resb   BUFSIZE
obuffer resb   BUFSIZE
```

```
section .text
align 4
err:
   push   dword 1    ; return failure
   sys.exit

align 4
global  _start
_start:
   add esp, byte 8 ; discard argc and argv[0]

   pop ecx
   jecxz   .init     ; no more arguments

   ; ECX contains the path to input file
   push   dword 0    ; O_RDONLY
   push   ecx
   sys.open
   jc  err    ; open failed

   add esp, byte 8
   mov [fd.in], eax

   pop ecx
   jecxz   .init     ; no more arguments

   ; ECX contains the path to output file
   push   dword 420   ; file mode (644 octal)
   push   dword 0200h | 0400h | 01h
   ; O_CREAT | O_TRUNC | O_WRONLY
   push   ecx
   sys.open
   jc  err

   add esp, byte 12
   mov [fd.out], eax

.init:
   sub eax, eax
   sub ebx, ebx
   sub ecx, ecx
   mov edi, obuffer
```

```
.loop:
   ; read a byte from input file or stdin
   call   getchar

   ; convert it to hex
   mov dl, al
   shr al, 4
   mov al, [hex+eax]
   call   putchar

   mov al, dl
   and al, 0Fh
   mov al, [hex+eax]
   call   putchar

   mov al, ' '
   cmp dl, 0Ah
   jne .put
   mov al, dl

.put:
   call   putchar
   cmp al, dl
   jne .loop
   call   write
   jmp short .loop

align 4
getchar:
   or  ebx, ebx
   jne .fetch

   call   read

.fetch:
   lodsb
   dec ebx
   ret

read:
   push   dword BUFSIZE
```

```
    mov esi, ibuffer
    push    esi
    push    dword [fd.in]
    sys.read
    add esp, byte 12
    mov ebx, eax
    or  eax, eax
    je  .done
    sub eax, eax
    ret

align 4
.done:
    call    write       ; flush output buffer

    ; close files
    push    dword [fd.in]
    sys.close

    push    dword [fd.out]
    sys.close

    ; return success
    push    dword 0
    sys.exit

align 4
putchar:
    stosb
    inc ecx
    cmp ecx, BUFSIZE
    je  write
    ret

align 4
write:
    sub edi, ecx    ; start of buffer
    push    ecx
    push    edi
    push    dword [fd.out]
    sys.write
    add esp, byte 12
```

```
    sub eax, eax
    sub ecx, ecx    ; buffer is empty now
    ret
```

In our .data section we now have two new variables, fd.in and fd.out. We store the input and output file descriptors here.

In the .text section we have replaced the references to stdin and stdout with [fd.in] and [fd.out].

The .text section now starts with a simple error handler, which does nothing but exit the program with a return value of 1. The error handler is before _start so we are within a short distance from where the errors occur.

Naturally, the program execution still begins at _start. First, we remove argc and argv[0] from the stack: They are of no interest to us (in this program, that is).

We pop argv[1] to ECX. This register is particularly suited for pointers, as we can handle NULL pointers with jecxz. If argv[1] is not NULL, we try to open the file named in the first argument. Otherwise, we continue the program as before: Reading from stdin, writing to stdout. If we fail to open the input file (e.g., it does not exist), we jump to the error handler and quit.

If all went well, we now check for the second argument. If it is there, we open the output file. Otherwise, we send the output to stdout. If we fail to open the output file (e.g., it exists and we do not have the write permission), we, again, jump to the error handler.

The rest of the code is the same as before, except we close the input and output files before exiting, and, as mentioned, we use [fd.in] and [fd.out].

Our executable is now a whopping 768 bytes long.

Can we still improve it? Of course! Every program can be improved. Here are a few ideas of what we could do:

- Have our error handler print a message to stderr.
- Add error handlers to the read and write functions.
- Close stdin when we open an input file, stdout when we open an output file.
- Add command line switches, such as -i and -o, so we can list the input and output files in any order, or perhaps read from stdin and write to a file.
- Print a usage message if command line arguments are incorrect.

I shall leave these enhancements as an exercise to the reader: You already know everything you need to know to implement them.

11.10. UNIX® Environment

An important UNIX® concept is the environment, which is defined by environment variables. Some are set by the system, others by you, yet others by the shell, or any program that loads another program.

11.10.1. How to Find Environment Variables

I said earlier that when a program starts executing, the stack contains argc followed by the NULL-terminated argv array, followed by something else. The "something else" is the environment, or, to be more precise, a NULL-terminated array of pointers to environment variables. This is often referred to as env.

The structure of env is the same as that of argv, a list of memory addresses followed by a NULL (0). In this case, there is no "envc"-we figure out where the array ends by searching for the final NULL.

The variables usually come in the name=value format, but sometimes the =value part may be missing. We need to account for that possibility.

11.10.2. webvars

I could just show you some code that prints the environment the same way the UNIX® env command does. But I thought it would be more interesting to write a simple assembly language CGI utility.

11.10.2.1. CGI: a Quick Overview

I have a detailed CGI tutorial on my web site, but here is a very quick overview of CGI:

- The web server communicates with the CGI program by setting environment variables.
- The CGI program sends its output to stdout. The web server reads it from there.
- It must start with an HTTP header followed by two blank lines.
- It then prints the HTML code, or whatever other type of data it is producing.

> While certain environment variables use standard names, others vary, depending on the web server. That makes webvars quite a useful diagnostic tool.

11.10.2.2. The Code

Our webvars program, then, must send out the HTTP header followed by some HTML mark-up. It then must read the environment variables one by one and send them out as part of the HTML page.

The code follows. I placed comments and explanations right inside the code:

```
;;;;;;; webvars.asm ;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
;
; Copyright (c) 2000 G. Adam Stanislav
; All rights reserved.
;
; Redistribution and use in source and binary forms, with or without
; modification, are permitted provided that the following conditions
; are met:
; 1. Redistributions of source code must retain the above copyright
;    notice, this list of conditions and the following disclaimer.
; 2. Redistributions in binary form must reproduce the above copyright
;    notice, this list of conditions and the following disclaimer in the
;    documentation and/or other materials provided with the distribution.
;
; THIS SOFTWARE IS PROVIDED BY THE AUTHOR AND CONTRIBUTORS ``AS IS'' AND
; ANY EXPRESS OR IMPLIED WARRANTIES, INCLUDING, BUT NOT LIMITED TO, THE
; IMPLIED WARRANTIES OF MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE
; ARE DISCLAIMED.  IN NO EVENT SHALL THE AUTHOR OR CONTRIBUTORS BE LIABLE
; FOR ANY DIRECT, INDIRECT, INCIDENTAL, SPECIAL, EXEMPLARY, OR CONSEQUENTIAL
; DAMAGES (INCLUDING, BUT NOT LIMITED TO, PROCUREMENT OF SUBSTITUTE GOODS
; OR SERVICES; LOSS OF USE, DATA, OR PROFITS; OR BUSINESS INTERRUPTION)
```

```
; HOWEVER CAUSED AND ON ANY THEORY OF LIABILITY, WHETHER IN CONTRACT, STRICT
; LIABILITY, OR TORT (INCLUDING NEGLIGENCE OR OTHERWISE) ARISING IN ANY WAY
; OUT OF THE USE OF THIS SOFTWARE, EVEN IF ADVISED OF THE POSSIBILITY OF
; SUCH DAMAGE.
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
;
; Version 1.0
;
; Started:  8-Dec-2000
; Updated:  8-Dec-2000
;
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
%include   'system.inc'

section .data
http   db  'Content-type: text/html', 0Ah, 0Ah
   db  '<?xml version="1.0" encoding="utf-8"?>', 0Ah
   db  '<!DOCTYPE html PUBLIC "-//W3C/DTD XHTML Strict//EN" '
   db  '"DTD/xhtml1-strict.dtd">', 0Ah
   db  '<html xmlns="http://www.w3.org/1999/xhtml" '
   db  'xml.lang="en" lang="en">', 0Ah
   db  '<head>', 0Ah
   db  '<title>Web Environment</title>', 0Ah
   db  '<meta name="author" content="G. Adam Stanislav" />', 0Ah
   db  '</head>', 0Ah, 0Ah
   db  '<body bgcolor="#ffffff" text="#000000" link="#0000ff" '
   db  'vlink="#840084" alink="#0000ff">', 0Ah
   db  '<div class="webvars">', 0Ah
   db  '<h1>Web Environment</h1>', 0Ah
   db  '<p>The following <b>environment variables</b> are defined '
   db  'on this web server:</p>', 0Ah, 0Ah
   db  '<table align="center" width="80" border="0" cellpadding="10" '
   db  'cellspacing="0" class="webvars">', 0Ah
httplen equ $-http
left   db  '<tr>', 0Ah
   db  '<td class="name"><tt>'
leftlen equ $-left
middle  db  '</tt></td>', 0Ah
   db  '<td class="value"><tt><b>'
midlen  equ $-middle
undef   db  '<i>(undefined)</i>'
undeflen   equ $-undef
```

```
right  db  '</b></tt></td>', 0Ah
  db  '</tr>', 0Ah
rightlen   equ $-right
wrap   db  '</table>', 0Ah
  db  '</div>', 0Ah
  db  '</body>', 0Ah
  db  '</html>', 0Ah, 0Ah
wraplen equ $-wrap

section .text
global  _start
_start:
  ; First, send out all the http and xhtml stuff that is
  ; needed before we start showing the environment
  push   dword httplen
  push   dword http
  push   dword stdout
  sys.write

  ; Now find how far on the stack the environment pointers
  ; are. We have 12 bytes we have pushed before "argc"
  mov eax, [esp+12]

  ; We need to remove the following from the stack:
  ;
  ;  The 12 bytes we pushed for sys.write
  ;  The  4 bytes of argc
  ;  The EAX*4 bytes of argv
  ;  The  4 bytes of the NULL after argv
  ;
  ; Total:
  ;  20 + eax * 4
  ;
  ; Because stack grows down, we need to ADD that many bytes
  ; to ESP.
  lea esp, [esp+20+eax*4]
  cld    ; This should already be the case, but let's be sure.

  ; Loop through the environment, printing it out
.loop:
  pop edi
  or  edi, edi   ; Done yet?
```

```
    je  near .wrap

    ; Print the left part of HTML
    push    dword leftlen
    push    dword left
    push    dword stdout
    sys.write

    ; It may be tempting to search for the '=' in the env string next.
    ; But it is possible there is no '=', so we search for the
    ; terminating NUL first.
    mov esi, edi    ; Save start of string
    sub ecx, ecx
    not ecx     ; ECX = FFFFFFFF
    sub eax, eax
repne   scasb
    not ecx     ; ECX = string length + 1
    mov ebx, ecx    ; Save it in EBX

    ; Now is the time to find '='
    mov edi, esi    ; Start of string
    mov al, '='
repne   scasb
    not ecx
    add ecx, ebx    ; Length of name

    push    ecx
    push    esi
    push    dword stdout
    sys.write

    ; Print the middle part of HTML table code
    push    dword midlen
    push    dword middle
    push    dword stdout
    sys.write

    ; Find the length of the value
    not ecx
    lea ebx, [ebx+ecx-1]

    ; Print "undefined" if 0
```

```
    or  ebx, ebx
    jne .value

    mov ebx, undeflen
    mov edi, undef

.value:
    push    ebx
    push    edi
    push    dword stdout
    sys.write

    ; Print the right part of the table row
    push    dword rightlen
    push    dword right
    push    dword stdout
    sys.write

    ; Get rid of the 60 bytes we have pushed
    add esp, byte 60

    ; Get the next variable
    jmp .loop

.wrap:
    ; Print the rest of HTML
    push    dword wraplen
    push    dword wrap
    push    dword stdout
    sys.write

    ; Return success
    push    dword 0
    sys.exit
```

This code produces a 1,396-byte executable. Most of it is data, i.e., the HTML mark-up we need to send out.

Assemble and link it as usual:

```
% nasm -f elf webvars.asm
% ld -s -o webvars webvars.o
```

To use it, you need to upload webvars to your web server. Depending on how your web server is set

up, you may have to store it in a special cgi-bin directory, or perhaps rename it with a .cgi extension.

Then you need to use your browser to view its output. To see its output on my web server, please go to http://www.int80h.org/webvars/. If curious about the additional environment variables present in a password protected web directory, go to http://www.int80h.org/private/, using the name asm and password programmer.

11.11. Working with Files

We have already done some basic file work: We know how to open and close them, how to read and write them using buffers. But UNIX® offers much more functionality when it comes to files. We will examine some of it in this section, and end up with a nice file conversion utility.

Indeed, let us start at the end, that is, with the file conversion utility. It always makes programming easier when we know from the start what the end product is supposed to do.

One of the first programs I wrote for UNIX® was tuc, a text-to-UNIX® file converter. It converts a text file from other operating systems to a UNIX® text file. In other words, it changes from different kind of line endings to the newline convention of UNIX®. It saves the output in a different file. Optionally, it converts a UNIX® text file to a DOS text file.

I have used tuc extensively, but always only to convert from some other OS to UNIX®, never the other way. I have always wished it would just overwrite the file instead of me having to send the output to a different file. Most of the time, I end up using it like this:

```
% tuc myfile tempfile
% mv tempfile myfile
```

It would be nice to have a ftuc, i.e., fast tuc, and use it like this:

```
% ftuc myfile
```

In this chapter, then, we will write ftuc in assembly language (the original tuc is in C), and study various file-oriented kernel services in the process.

At first sight, such a file conversion is very simple: All you have to do is strip the carriage returns, right?

If you answered yes, think again: That approach will work most of the time (at least with MS DOS text files), but will fail occasionally.

The problem is that not all non UNIX® text files end their line with the carriage return / line feed sequence. Some use carriage returns without line feeds. Others combine several blank lines into a single carriage return followed by several line feeds. And so on.

A text file converter, then, must be able to handle any possible line endings:

- carriage return / line feed
- carriage return
- line feed / carriage return
- line feed

It should also handle files that use some kind of a combination of the above (e.g., carriage return followed by several line feeds).

11.11.1. Finite State Machine

The problem is easily solved by the use of a technique called finite state machine, originally developed by the designers of digital electronic circuits. A finite state machine is a digital circuit whose output is dependent not only on its input but on its previous input, i.e., on its state. The microprocessor is an example of a finite state machine: Our assembly language code is assembled to machine language in which some assembly language code produces a single byte of machine language, while others produce several bytes. As the microprocessor fetches the bytes from the memory one by one, some of them simply change its state rather than produce some output. When all the bytes of the op code are fetched, the microprocessor produces some output, or changes the value of a register, etc.

Because of that, all software is essentially a sequence of state instructions for the microprocessor. Nevertheless, the concept of finite state machine is useful in software design as well.

Our text file converter can be designer as a finite state machine with three possible states. We could call them states 0-2, but it will make our life easier if we give them symbolic names:

- ordinary
- cr
- lf

Our program will start in the ordinary state. During this state, the program action depends on its input as follows:

- If the input is anything other than a carriage return or line feed, the input is simply passed on to the output. The state remains unchanged.
- If the input is a carriage return, the state is changed to cr. The input is then discarded, i.e., no output is made.
- If the input is a line feed, the state is changed to lf. The input is then discarded.

Whenever we are in the cr state, it is because the last input was a carriage return, which was unprocessed. What our software does in this state again depends on the current input:

- If the input is anything other than a carriage return or line feed, output a line feed, then output the input, then change the state to ordinary.
- If the input is a carriage return, we have received two (or more) carriage returns in a row. We discard the input, we output a line feed, and leave the state unchanged.
- If the input is a line feed, we output the line feed and change the state to ordinary. Note that this is not the same as the first case above - if we tried to combine them, we would be outputting two line feeds instead of one.

Finally, we are in the lf state after we have received a line feed that was not preceded by a carriage return. This will happen when our file already is in UNIX® format, or whenever several lines in a row are expressed by a single carriage return followed by several line feeds, or when line ends with a line feed / carriage return sequence. Here is how we need to handle our input in this state:

- If the input is anything other than a carriage return or line feed, we output a line feed, then output the input, then change the state to ordinary. This is exactly the same action as in the cr state upon receiving the same kind of input.
- If the input is a carriage return, we discard the input, we output a line feed, then change the state to ordinary.
- If the input is a line feed, we output the line feed, and leave the state unchanged.

11.11.1.1. The Final State

The above finite state machine works for the entire file, but leaves the possibility that the final line end will be ignored. That will happen whenever the file ends with a single carriage return or a single line feed. I did not think of it when I wrote tuc, just to discover that occasionally it strips the last line

ending.

This problem is easily fixed by checking the state after the entire file was processed. If the state is not ordinary, we simply need to output one last line feed.

Now that we have expressed our algorithm as a finite state machine, we could easily design a dedicated digital electronic circuit (a "chip") to do the conversion for us. Of course, doing so would be considerably more expensive than writing an assembly language program.

11.11.1.2. The Output Counter

Because our file conversion program may be combining two characters into one, we need to use an output counter. We initialize it to 0, and increase it every time we send a character to the output. At the end of the program, the counter will tell us what size we need to set the file to.

11.11.2. Implementing FSM in Software

The hardest part of working with a finite state machine is analyzing the problem and expressing it as a finite state machine. That accomplished, the software almost writes itself.

In a high-level language, such as C, there are several main approaches. One is to use a switch statement which chooses what function should be run. For example,

```
switch (state) {
  default:
  case REGULAR:
    regular(inputchar);
    break;
  case CR:
    cr(inputchar);
    break;
  case LF:
    lf(inputchar);
    break;
  }
```

Another approach is by using an array of function pointers, something like this:

```
(output[state])(inputchar);
```

Yet another is to have state be a function pointer, set to point at the appropriate function:

```
(*state)(inputchar);
```

This is the approach we will use in our program because it is very easy to do in assembly language, and very fast, too. We will simply keep the address of the right procedure in EBX, and then just issue:

```
call   ebx
```

This is possibly faster than hardcoding the address in the code because the microprocessor does not have to fetch the address from the memory-it is already stored in one of its registers. I said possibly because with the caching modern microprocessors do, either way may be equally fast.

11.11.3. Memory Mapped Files

Because our program works on a single file, we cannot use the approach that worked for us before, i.e., to read from an input file and to write to an output file.

UNIX® allows us to map a file, or a section of a file, into memory. To do that, we first need to open the file with the appropriate read/write flags. Then we use the mmap system call to map it into the memory. One nice thing about mmap is that it automatically works with virtual memory: We can map more of the file into the memory than we have physical memory available, yet still access it through regular memory op codes, such as mov, lods, and stos. Whatever changes we make to the memory image of the file will be written to the file by the system. We do not even have to keep the file open: As long as it stays mapped, we can read from it and write to it.

The 32-bit Intel microprocessors can access up to four gigabytes of memory - physical or virtual. The FreeBSD system allows us to use up to a half of it for file mapping.

For simplicity sake, in this tutorial we will only convert files that can be mapped into the memory in their entirety. There are probably not too many text files that exceed two gigabytes in size. If our program encounters one, it will simply display a message suggesting we use the original tuc instead.

If you examine your copy of syscalls.master, you will find two separate syscalls named mmap. This is because of evolution of UNIX®: There was the traditional BSD mmap, syscall 71. That one was superseded by the POSIX® mmap, syscall 197. The FreeBSD system supports both because older programs were written by using the original BSD version. But new software uses the POSIX® version, which is what we will use.

The syscalls.master lists the POSIX® version like this:

```
197 STD BSD { caddr_t mmap(caddr_t addr, size_t len, int prot, \
        int flags, int fd, long pad, off_t pos); }
```

This differs slightly from what mmap(2) says. That is because mmap(2) describes the C version.

The difference is in the long pad argument, which is not present in the C version. However, the FreeBSD syscalls add a 32-bit pad after pushing a 64-bit argument. In this case, off_t is a 64-bit value.

When we are finished working with a memory-mapped file, we unmap it with the munmap syscall:

For an in-depth treatment of mmap, see W. Richard Stevens' Unix Network Programming, Volume 2, Chapter 12.

11.11.4. Determining File Size

Because we need to tell mmap how many bytes of the file to map into the memory, and because we want to map the entire file, we need to determine the size of the file.

We can use the fstat syscall to get all the information about an open file that the system can give us. That includes the file size.

Again, syscalls.master lists two versions of fstat, a traditional one (syscall 62), and a POSIX® one (syscall 189). Naturally, we will use the POSIX® version:

```
189 STD POSIX   { int fstat(int fd, struct stat *sb); }
```

This is a very straightforward call: We pass to it the address of a stat structure and the descriptor of an open file. It will fill out the contents of the stat structure.

I do, however, have to say that I tried to declare the stat structure in the .bss section, and fstat did not like it: It set the carry flag indicating an error. After I changed the code to allocate the structure on the stack, everything was working fine.

11.11.5. Changing the File Size

Because our program may combine carriage return / line feed sequences into straight line feeds, our output may be smaller than our input. However, since we are placing our output into the same file we read the input from, we may have to change the size of the file.

The ftruncate system call allows us to do just that. Despite its somewhat misleading name, the ftruncate system call can be used to both truncate the file (make it smaller) and to grow it.

And yes, we will find two versions of ftruncate in syscalls.master, an older one (130), and a newer one (201). We will use the newer one:

```
201 STD BSD { int ftruncate(int fd, int pad, off_t length); }
```

Please note that this one contains a int pad again.

11.11.6. ftuc

We now know everything we need to write ftuc. We start by adding some new lines in system.inc. First, we define some constants and structures, somewhere at or near the beginning of the file:

```
;;;;;;; open flags
%define O_RDONLY   0
%define O_WRONLY   1
%define O_RDWR  2

;;;;;;; mmap flags
%define PROT_NONE   0
%define PROT_READ   1
%define PROT_WRITE  2
%define PROT_EXEC   4
;;
%define MAP_SHARED  0001h
%define MAP_PRIVATE 0002h

;;;;;;; stat structure
struc   stat
```

```
st_dev    resd   1  ; = 0
st_ino    resd   1  ; = 4
st_mode   resw   1  ; = 8, size is 16 bits
st_nlink  resw   1  ; = 10, ditto
st_uid    resd   1  ; = 12
st_gid    resd   1  ; = 16
st_rdev   resd   1  ; = 20
st_atime  resd   1  ; = 24
st_atimensec  resd   1  ; = 28
st_mtime  resd   1  ; = 32
st_mtimensec  resd   1  ; = 36
st_ctime  resd   1  ; = 40
st_ctimensec  resd   1  ; = 44
st_size   resd   2  ; = 48, size is 64 bits
st_blocks  resd   2  ; = 56, ditto
st_blksize  resd   1  ; = 64
st_flags  resd   1  ; = 68
st_gen    resd   1  ; = 72
st_lspare  resd   1  ; = 76
st_qspare  resd   4  ; = 80
endstruc
```

We define the new syscalls:

```
%define SYS_mmap   197
%define SYS_munmap  73
%define SYS_fstat   189
%define SYS_ftruncate   201
```

We add the macros for their use:

```
%macro  sys.mmap   0
  system  SYS_mmap
%endmacro

%macro  sys.munmap  0
  system  SYS_munmap
%endmacro

%macro  sys.ftruncate  0
  system  SYS_ftruncate
%endmacro
```

```
%macro  sys.fstat  0
   system  SYS_fstat
%endmacro
```

And here is our code:

```
;;;;;;; Fast Text-to-Unix Conversion (ftuc.asm) ;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
;;
;; Started: 21-Dec-2000
;; Updated: 22-Dec-2000
;;
;; Copyright 2000 G. Adam Stanislav.
;; All rights reserved.
;;
;;;;;;; v.1 ;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
%include    'system.inc'

section .data
   db  'Copyright 2000 G. Adam Stanislav.', 0Ah
   db  'All rights reserved.', 0Ah
usg db  'Usage: ftuc filename', 0Ah
usglen  equ $-usg
co  db  "ftuc: Can't open file.", 0Ah
colen   equ $-co
fae db  'ftuc: File access error.', 0Ah
faelen  equ $-fae
ftl db  'ftuc: File too long, use regular tuc instead.', 0Ah
ftllen  equ $-ftl
mae db  'ftuc: Memory allocation error.', 0Ah
maelen  equ $-mae

section .text

align 4
memerr:
   push    dword maelen
   push    dword mae
   jmp short error

align 4
toolong:
```

```
    push    dword ftllen
    push    dword ftl
    jmp short error

align 4
facerr:
    push    dword faelen
    push    dword fae
    jmp short error

align 4
cantopen:
    push    dword colen
    push    dword co
    jmp short error

align 4
usage:
    push    dword usglen
    push    dword usg

error:
    push    dword stderr
    sys.write

    push    dword 1
    sys.exit

align 4
global  _start
_start:
    pop eax     ; argc
    pop eax     ; program name
    pop ecx     ; file to convert
    jecxz   usage

    pop eax
    or  eax, eax    ; Too many arguments?
    jne usage

    ; Open the file
    push    dword O_RDWR
```

```
push   ecx
sys.open
jc  cantopen

mov ebp, eax   ; Save fd

sub esp, byte stat_size
mov ebx, esp

; Find file size
push   ebx
push   ebp    ; fd
sys.fstat
jc  facerr

mov edx, [ebx + st_size + 4]

; File is too long if EDX != 0 ...
or  edx, edx
jne near toolong
mov ecx, [ebx + st_size]
; ... or if it is above 2 GB
or  ecx, ecx
js  near toolong

; Do nothing if the file is 0 bytes in size
jecxz  .quit

; Map the entire file in memory
push   edx
push   edx    ; starting at offset 0
push   edx    ; pad
push   ebp    ; fd
push   dword MAP_SHARED
push   dword PROT_READ | PROT_WRITE
push   ecx    ; entire file size
push   edx    ; let system decide on the address
sys.mmap
jc  near memerr

mov edi, eax
mov esi, eax
```

```
    push    ecx     ; for SYS_munmap
    push    edi

    ; Use EBX for state machine
    mov ebx, ordinary
    mov ah, 0Ah
    cld

.loop:
    lodsb
    call    ebx
    loop    .loop

    cmp ebx, ordinary
    je  .filesize

    ; Output final lf
    mov al, ah
    stosb
    inc edx

.filesize:
    ; truncate file to new size
    push    dword 0     ; high dword
    push    edx     ; low dword
    push    eax     ; pad
    push    ebp
    sys.ftruncate

    ; close it (ebp still pushed)
    sys.close

    add esp, byte 16
    sys.munmap

.quit:
    push    dword 0
    sys.exit

align 4
ordinary:
    cmp al, 0Dh
```

```
    je  .cr

    cmp al, ah
    je  .lf

    stosb
    inc edx
    ret

align 4
.cr:
    mov ebx, cr
    ret

align 4
.lf:
    mov ebx, lf
    ret

align 4
cr:
    cmp al, 0Dh
    je  .cr

    cmp al, ah
    je  .lf

    xchg    al, ah
    stosb
    inc edx

    xchg    al, ah
    ; fall through

.lf:
    stosb
    inc edx
    mov ebx, ordinary
    ret

align 4
.cr:
```

```
    mov al, ah
    stosb
    inc edx
    ret

align 4
lf:
    cmp al, ah
    je  .lf

    cmp al, 0Dh
    je  .cr

    xchg    al, ah
    stosb
    inc edx

    xchg    al, ah
    stosb
    inc edx
    mov ebx, ordinary
    ret

align 4
.cr:
    mov ebx, ordinary
    mov al, ah
    ; fall through

.lf:
    stosb
    inc edx
    ret
```

Do not use this program on files stored on a disk formatted by MS-DOS® or Windows®. There seems to be a subtle bug in the FreeBSD code when using mmap on these drives mounted under FreeBSD: If the file is over a certain size, mmap will just fill the memory with zeros, and then copy them to the file overwriting its contents.

11.12. One-Pointed Mind

As a student of Zen, I like the idea of a one-pointed mind: Do one thing at a time, and do it well.

This, indeed, is very much how UNIX® works as well. While a typical Windows® application is

attempting to do everything imaginable (and is, therefore, riddled with bugs), a typical UNIX® program does only one thing, and it does it well.

The typical UNIX® user then essentially assembles his own applications by writing a shell script which combines the various existing programs by piping the output of one program to the input of another.

When writing your own UNIX® software, it is generally a good idea to see what parts of the problem you need to solve can be handled by existing programs, and only write your own programs for that part of the problem that you do not have an existing solution for.

11.12.1. CSV

I will illustrate this principle with a specific real-life example I was faced with recently:

I needed to extract the 11th field of each record from a database I downloaded from a web site. The database was a CSV file, i.e., a list of comma-separated values. That is quite a standard format for sharing data among people who may be using different database software.

The first line of the file contains the list of various fields separated by commas. The rest of the file contains the data listed line by line, with values separated by commas.

I tried awk, using the comma as a separator. But because several lines contained a quoted comma, awk was extracting the wrong field from those lines.

Therefore, I needed to write my own software to extract the 11th field from the CSV file. However, going with the UNIX® spirit, I only needed to write a simple filter that would do the following:

- Remove the first line from the file;
- Change all unquoted commas to a different character;
- Remove all quotation marks.

Strictly speaking, I could use sed to remove the first line from the file, but doing so in my own program was very easy, so I decided to do it and reduce the size of the pipeline.

At any rate, writing a program like this took me about 20 minutes. Writing a program that extracts the 11th field from the CSV file would take a lot longer, and I could not reuse it to extract some other field from some other database.

This time I decided to let it do a little more work than a typical tutorial program would:

- It parses its command line for options;
- It displays proper usage if it finds wrong arguments;
- It produces meaningful error messages.

Here is its usage message:

```
Usage: csv [-t<delim>] [-c<comma>] [-p] [-o <outfile>] [-i <infile>]
```

All parameters are optional, and can appear in any order.

The -t parameter declares what to replace the commas with. The tab is the default here. For example, -t; will replace all unquoted commas with semicolons.

I did not need the -c option, but it may come in handy in the future. It lets me declare that I want a character other than a comma replaced with something else. For example, -c@ will replace all at signs (useful if you want to split a list of email addresses to their user names and domains).

The -p option preserves the first line, i.e., it does not delete it. By default, we delete the first line because in a CSV file it contains the field names rather than data.

The -i and -o options let me specify the input and the output files. Defaults are stdin and stdout, so this is a regular UNIX® filter.

I made sure that both -i filename and -ifilename are accepted. I also made sure that only one input and one output files may be specified.

To get the 11th field of each record, I can now do:

```
% csv '-t;' data.csv | awk '-F;' '{print $11}'
```

The code stores the options (except for the file descriptors) in EDX: The comma in DH, the new separator in DL, and the flag for the -p option in the highest bit of EDX, so a check for its sign will give us a quick decision what to do.

Here is the code:

```
;;;;;;; csv.asm ;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
;
; Convert a comma-separated file to a something-else separated file.
;
; Started:  31-May-2001
; Updated:   1-Jun-2001
;
; Copyright (c) 2001 G. Adam Stanislav
; All rights reserved.
;
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;

%include    'system.inc'

%define BUFSIZE 2048

section .data
fd.in   dd  stdin
fd.out  dd  stdout
usg db  'Usage: csv [-t<delim>] [-c<comma>] [-p] [-o <outfile>] [-i <infile>]', 0Ah
usglen  equ $-usg
iemsg   db  "csv: Can't open input file", 0Ah
iemlen  equ $-iemsg
oemsg   db  "csv: Can't create output file", 0Ah
oemlen  equ $-oemsg

section .bss
ibuffer resb    BUFSIZE
```

```
obuffer resb    BUFSIZE

section .text
align 4
ierr:
    push    dword iemlen
    push    dword iemsg
    push    dword stderr
    sys.write
    push    dword 1     ; return failure
    sys.exit

align 4
oerr:
    push    dword oemlen
    push    dword oemsg
    push    dword stderr
    sys.write
    push    dword 2
    sys.exit

align 4
usage:
    push    dword usglen
    push    dword usg
    push    dword stderr
    sys.write
    push    dword 3
    sys.exit

align 4
global  _start
_start:
    add esp, byte 8 ; discard argc and argv[0]
    mov edx, (',' << 8) | 9

.arg:
    pop ecx
    or  ecx, ecx
    je  near .init      ; no more arguments

    ; ECX contains the pointer to an argument
```

```
    cmp byte [ecx], '-'
    jne usage

    inc ecx
    mov ax, [ecx]

.o:
    cmp al, 'o'
    jne .i

    ; Make sure we are not asked for the output file twice
    cmp dword [fd.out], stdout
    jne usage

    ; Find the path to output file - it is either at [ECX+1],
    ; i.e., -ofile --
    ; or in the next argument,
    ; i.e., -o file

    inc ecx
    or  ah, ah
    jne .openoutput
    pop ecx
    jecxz   usage

.openoutput:
    push    dword 420   ; file mode (644 octal)
    push    dword 0200h | 0400h | 01h
    ; O_CREAT | O_TRUNC | O_WRONLY
    push    ecx
    sys.open
    jc  near oerr

    add esp, byte 12
    mov [fd.out], eax
    jmp short .arg

.i:
    cmp al, 'i'
    jne .p

    ; Make sure we are not asked twice
```

```
    cmp dword [fd.in], stdin
    jne near usage

    ; Find the path to the input file
    inc ecx
    or  ah, ah
    jne .openinput
    pop ecx
    or  ecx, ecx
    je near usage

.openinput:
    push    dword 0    ; O_RDONLY
    push    ecx
    sys.open
    jc  near ierr      ; open failed

    add esp, byte 8
    mov [fd.in], eax
    jmp .arg

.p:
    cmp al, 'p'
    jne .t
    or  ah, ah
    jne near usage
    or  edx, 1 << 31
    jmp .arg

.t:
    cmp al, 't'    ; redefine output delimiter
    jne .c
    or  ah, ah
    je  near usage
    mov dl, ah
    jmp .arg

.c:
    cmp al, 'c'
    jne near usage
    or  ah, ah
    je  near usage
```

```
    mov dh, ah
    jmp .arg

align 4
.init:
    sub eax, eax
    sub ebx, ebx
    sub ecx, ecx
    mov edi, obuffer

    ; See if we are to preserve the first line
    or  edx, edx
    js  .loop

.firstline:
    ; get rid of the first line
    call    getchar
    cmp al, 0Ah
    jne .firstline

.loop:
    ; read a byte from stdin
    call    getchar

    ; is it a comma (or whatever the user asked for)?
    cmp al, dh
    jne .quote

    ; Replace the comma with a tab (or whatever the user wants)
    mov al, dl

.put:
    call    putchar
    jmp short .loop

.quote:
    cmp al, '"'
    jne .put

    ; Print everything until you get another quote or EOL. If it
    ; is a quote, skip it. If it is EOL, print it.
.qloop:
```

```
    call   getchar
    cmp al, ""
    je  .loop

    cmp al, 0Ah
    je  .put

    call   putchar
    jmp short .qloop

align 4
getchar:
    or  ebx, ebx
    jne .fetch

    call   read

.fetch:
    lodsb
    dec ebx
    ret

read:
    jecxz   .read
    call    write

.read:
    push    dword BUFSIZE
    mov esi, ibuffer
    push    esi
    push    dword [fd.in]
    sys.read
    add esp, byte 12
    mov ebx, eax
    or  eax, eax
    je  .done
    sub eax, eax
    ret

align 4
.done:
    call    write      ; flush output buffer
```

```
    ; close files
    push    dword [fd.in]
    sys.close

    push    dword [fd.out]
    sys.close

    ; return success
    push    dword 0
    sys.exit

align 4
putchar:
    stosb
    inc ecx
    cmp ecx, BUFSIZE
    je  write
    ret

align 4
write:
    jecxz   .ret    ; nothing to write
    sub edi, ecx    ; start of buffer
    push    ecx
    push    edi
    push    dword [fd.out]
    sys.write
    add esp, byte 12
    sub eax, eax
    sub ecx, ecx    ; buffer is empty now
.ret:
    ret
```

Much of it is taken from hex.asm above. But there is one important difference: I no longer call write whenever I am outputting a line feed. Yet, the code can be used interactively.

I have found a better solution for the interactive problem since I first started writing this chapter. I wanted to make sure each line is printed out separately only when needed. After all, there is no need to flush out every line when used non-interactively.

The new solution I use now is to call write every time I find the input buffer empty. That way, when running in the interactive mode, the program reads one line from the user's keyboard, processes it, and sees its input buffer is empty. It flushes its output and reads the next line.

11.12.1.1. The Dark Side of Buffering

This change prevents a mysterious lockup in a very specific case. I refer to it as the dark side of buffering, mostly because it presents a danger that is not quite obvious.

It is unlikely to happen with a program like the csv above, so let us consider yet another filter: In this case we expect our input to be raw data representing color values, such as the red, green, and blue intensities of a pixel. Our output will be the negative of our input.

Such a filter would be very simple to write. Most of it would look just like all the other filters we have written so far, so I am only going to show you its inner loop:

```
.loop:
  call   getchar
  not al     ; Create a negative
  call   putchar
  jmp short .loop
```

Because this filter works with raw data, it is unlikely to be used interactively.

But it could be called by image manipulation software. And, unless it calls write before each call to read, chances are it will lock up.

Here is what might happen:

1. The image editor will load our filter using the C function popen().
2. It will read the first row of pixels from a bitmap or pixmap.
3. It will write the first row of pixels to the pipe leading to the fd.in of our filter.
4. Our filter will read each pixel from its input, turn it to a negative, and write it to its output buffer.
5. Our filter will call getchar to fetch the next pixel.
6. getchar will find an empty input buffer, so it will call read.
7. read will call the SYS_read system call.
8. The kernel will suspend our filter until the image editor sends more data to the pipe.
9. The image editor will read from the other pipe, connected to the fd.out of our filter so it can set the first row of the output image before it sends us the second row of the input.
10. The kernel suspends the image editor until it receives some output from our filter, so it can pass it on to the image editor.

At this point our filter waits for the image editor to send it more data to process, while the image editor is waiting for our filter to send it the result of the processing of the first row. But the result sits in our output buffer.

The filter and the image editor will continue waiting for each other forever (or, at least, until they are killed). Our software has just entered a race condition.

This problem does not exist if our filter flushes its output buffer before asking the kernel for more input data.

11.13. Using the FPU

Strangely enough, most of assembly language literature does not even mention the existence of the FPU, or floating point unit, let alone discuss programming it.

Yet, never does assembly language shine more than when we create highly optimized FPU code by doing things that can be done only in assembly language.

11.13.1. Organization of the FPU

The FPU consists of 8 80-bit floating-point registers. These are organized in a stack fashion-you can push a value on TOS (top of stack) and you can pop it.

That said, the assembly language op codes are not push and pop because those are already taken.

You can push a value on TOS by using fld, fild, and fbld. Several other op codes let you push many common constants-such as pi-on the TOS.

Similarly, you can pop a value by using fst, fstp, fist, fistp, and fbstp. Actually, only the op codes that end with a p will literally pop the value, the rest will store it somewhere else without removing it from the TOS.

We can transfer the data between the TOS and the computer memory either as a 32-bit, 64-bit, or 80-bit real, a 16-bit, 32-bit, or 64-bit integer, or an 80-bit packed decimal.

The 80-bit packed decimal is a special case of binary coded decimal which is very convenient when converting between the ASCII representation of data and the internal data of the FPU. It allows us to use 18 significant digits.

No matter how we represent data in the memory, the FPU always stores it in the 80-bit real format in its registers.

Its internal precision is at least 19 decimal digits, so even if we choose to display results as ASCII in the full 18-digit precision, we are still showing correct results.

We can perform mathematical operations on the TOS: We can calculate its sine, we can scale it (i.e., we can multiply or divide it by a power of 2), we can calculate its base-2 logarithm, and many other things.

We can also multiply or divide it by, add it to, or subtract it from, any of the FPU registers (including itself).

The official Intel op code for the TOS is st, and for the registers st(0)-st(7). st and st(0), then, refer to the same register.

For whatever reasons, the original author of nasm has decided to use different op codes, namely st0-st7. In other words, there are no parentheses, and the TOS is always st0, never just st.

11.13.1.1. The Packed Decimal Format

The packed decimal format uses 10 bytes (80 bits) of memory to represent 18 digits. The number represented there is always an integer.

You can use it to get decimal places by multiplying the TOS by a power of 10 first.

The highest bit of the highest byte (byte 9) is the sign bit: If it is set, the number is negative, otherwise, it is positive. The rest of the bits of this byte are unused/ignored.

The remaining 9 bytes store the 18 digits of the number: 2 digits per byte.

The more significant digit is stored in the high nibble (4 bits), the less significant digit in the low

nibble.

That said, you might think that -1234567 would be stored in the memory like this (using hexadecimal notation):

```
80 00 00 00 00 00 01 23 45 67
```

Alas it is not! As with everything else of Intel make, even the packed decimal is little-endian.

That means our -1234567 is stored like this:

```
67 45 23 01 00 00 00 00 00 80
```

Remember that, or you will be pulling your hair out in desperation!

The book to read-if you can find it-is Richard Startz' 8087/80287/80387 for the IBM PC & Compatibles. Though it does seem to take the fact about the little-endian storage of the packed decimal for granted. I kid you not about the desperation of trying to figure out what was wrong with the filter I show below before it occurred to me I should try the little-endian order even for this type of data.

11.13.2. Excursion to Pinhole Photography

To write meaningful software, we must not only understand our programming tools, but also the field we are creating software for.

Our next filter will help us whenever we want to build a pinhole camera, so, we need some background in pinhole photography before we can continue.

11.13.2.1. The Camera

The easiest way to describe any camera ever built is as some empty space enclosed in some lightproof material, with a small hole in the enclosure.

The enclosure is usually sturdy (e.g., a box), though sometimes it is flexible (the bellows). It is quite dark inside the camera. However, the hole lets light rays in through a single point (though in some cases there may be several). These light rays form an image, a representation of whatever is outside the camera, in front of the hole.

If some light sensitive material (such as film) is placed inside the camera, it can capture the image.

The hole often contains a lens, or a lens assembly, often called the objective.

11.13.2.2. The Pinhole

But, strictly speaking, the lens is not necessary: The original cameras did not use a lens but a pinhole. Even today, pinholes are used, both as a tool to study how cameras work, and to achieve a special kind of image.

The image produced by the pinhole is all equally sharp. Or blurred. There is an ideal size for a pinhole: If it is either larger or smaller, the image loses its sharpness.

11.13.2.3. Focal Length

This ideal pinhole diameter is a function of the square root of focal length, which is the distance of the pinhole from the film.

```
D = PC * sqrt(FL)
```

In here, D is the ideal diameter of the pinhole, FL is the focal length, and PC is a pinhole constant. According to Jay Bender, its value is 0.04, while Kenneth Connors has determined it to be 0.037. Others have proposed other values. Plus, this value is for the daylight only: Other types of light will require a different constant, whose value can only be determined by experimentation.

11.13.2.4. The F-Number

The f-number is a very useful measure of how much light reaches the film. A light meter can determine that, for example, to expose a film of specific sensitivity with f5.6 mkay require the exposure to last 1/1000 sec.

It does not matter whether it is a 35-mm camera, or a 6x9cm camera, etc. As long as we know the f-number, we can determine the proper exposure.

The f-number is easy to calculate:

```
F = FL / D
```

In other words, the f-number equals the focal length divided by the diameter of the pinhole. It also means a higher f-number either implies a smaller pinhole or a larger focal distance, or both. That, in turn, implies, the higher the f-number, the longer the exposure has to be.

Furthermore, while pinhole diameter and focal distance are one-dimensional measurements, both, the film and the pinhole, are two-dimensional. That means that if you have measured the exposure at f-number A as t, then the exposure at f-number B is:

$$t * (B / A)^2$$

11.13.2.5. Normalized F-Number

While many modern cameras can change the diameter of their pinhole, and thus their f-number, quite smoothly and gradually, such was not always the case.

To allow for different f-numbers, cameras typically contained a metal plate with several holes of different sizes drilled to them.

Their sizes were chosen according to the above formula in such a way that the resultant f-number was one of standard f-numbers used on all cameras everywhere. For example, a very old Kodak Duaflex IV camera in my possession has three such holes for f-numbers 8, 11, and 16.

A more recently made camera may offer f-numbers of 2.8, 4, 5.6, 8, 11, 16, 22, and 32 (as well as others). These numbers were not chosen arbitrarily: They all are powers of the square root of 2, though they may be rounded somewha.

11.13.2.6. The F-Stop

A typical camera is designed in such a way that setting any of the normalized f-numbers changes the feel of the dial. It will naturally stop in that position. Because of that, these positions of the dial are called f-stops.

Since the f-numbers at each stop are powers of the square root of 2, moving the dial by 1 stop will double the amount of light required for proper exposure. Moving it by 2 stops will quadruple the required exposure. Moving the dial by 3 stops will require the increase in exposure 8 times, etc.

11.13.3. Designing the Pinhole Software

We are now ready to decide what exactly we want our pinhole software to do.

11.13.3.1. Processing Program Input

Since its main purpose is to help us design a working pinhole camera, we will use the focal length as the input to the program. This is something we can determine without software: Proper focal length is determined by the size of the film and by the need to shoot "regular" pictures, wide angle pictures, or telephoto pictures.

Most of the programs we have written so far worked with individual characters, or bytes, as their input: The hex program converted individual bytes into a hexadecimal number, the csv program either let a character through, or deleted it, or changed it to a different character, etc.

One program, ftuc used the state machine to consider at most two input bytes at a time.

But our pinhole program cannot just work with individual characters, it has to deal with larger syntactic units.

For example, if we want the program to calculate the pinhole diameter (and other values we will discuss later) at the focal lengths of 100 mm, 150 mm, and 210 mm, we may want to enter something like this:

```
100, 150, 210
```

Our program needs to consider more than a single byte of input at a time. When it sees the first 1, it must understand it is seeing the first digit of a decimal number. When it sees the 0 and the other 0, it must know it is seeing more digits of the same number.

When it encounters the first comma, it must know it is no longer receiving the digits of the first number. It must be able to convert the digits of the first number into the value of 100. And the digits of the second number into the value of 150. And, of course, the digits of the third number into the numeric value of 210.

We need to decide what delimiters to accept: Do the input numbers have to be separated by a comma? If so, how do we treat two numbers separated by something else?

Personally, I like to keep it simple. Something either is a number, so I process it. Or it is not a number, so I discard it. I do not like the computer complaining about me typing in an extra character when it is obvious that it is an extra character. Duh!

Plus, it allows me to break up the monotony of computing and type in a query instead of just a number:

```
What is the best pinhole diameter for the
    focal length of 150?
```

There is no reason for the computer to spit out a number of complaints:

```
Syntax error: What
Syntax error: is
Syntax error: the
Syntax error: best
```

Et cetera, et cetera, et cetera.

Secondly, I like the # character to denote the start of a comment which extends to the end of the line. This does not take too much effort to code, and lets me treat input files for my software as executable scripts.

In our case, we also need to decide what units the input should come in: We choose millimeters because that is how most photographers measure the focus length.

Finally, we need to decide whether to allow the use of the decimal point (in which case we must also consider the fact that much of the world uses a decimal comma).

In our case allowing for the decimal point/comma would offer a false sense of precision: There is little if any noticeable difference between the focus lengths of 50 and 51, so allowing the user to input something like 50.5 is not a good idea. This is my opinion, mind you, but I am the one writing this program. You can make other choices in yours, of course.

11.13.3.2. Offering Options

The most important thing we need to know when building a pinhole camera is the diameter of the pinhole. Since we want to shoot sharp images, we will use the above formula to calculate the pinhole diameter from focal length. As experts are offering several different values for the PC constant, we will need to have the choice.

It is traditional in UNIX® programming to have two main ways of choosing program parameters, plus to have a default for the time the user does not make a choice.

Why have two ways of choosing?

One is to allow a (relatively) permanent choice that applies automatically each time the software is run without us having to tell it over and over what we want it to do.

The permanent choices may be stored in a configuration file, typically found in the user's home directory. The file usually has the same name as the application but is started with a dot. Often "rc" is added to the file name. So, ours could be ~/.pinhole or ~/.pinholerc. (The ~/ means current user's home directory.)

The configuration file is used mostly by programs that have many configurable parameters. Those that have only one (or a few) often use a different method: They expect to find the parameter in an environment variable. In our case, we might look at an environment variable named PINHOLE.

Usually, a program uses one or the other of the above methods. Otherwise, if a configuration file said one thing, but an environment variable another, the program might get confused (or just too complicated).

Because we only need to choose one such parameter, we will go with the second method and search the environment for a variable named PINHOLE.

The other way allows us to make ad hoc decisions: "Though I usually want you to use 0.039, this time I want 0.03872." In other words, it allows us to override the permanent choice.

This type of choice is usually done with command line parameters.

Finally, a program always needs a default. The user may not make any choices. Perhaps he does not know what to choose. Perhaps he is "just browsing." Preferably, the default will be the value most users would choose anyway. That way they do not need to choose. Or, rather, they can choose the default without an additional effort.

Given this system, the program may find conflicting options, and handle them this way:

1. If it finds an ad hoc choice (e.g., command line parameter), it should accept that choice. It must ignore any permanent choice and any default.

2. Otherwise, if it finds a permanent option (e.g., an environment variable), it should accept it, and ignore the default.
3. Otherwise, it should use the default.

We also need to decide what format our PC option should have.

At first site, it seems obvious to use the PINHOLE=0.04 format for the environment variable, and -p0.04 for the command line.

Allowing that is actually a security risk. The PC constant is a very small number. Naturally, we will test our software using various small values of PC. But what will happen if someone runs the program choosing a huge value?

It may crash the program because we have not designed it to handle huge numbers.

Or, we may spend more time on the program so it can handle huge numbers. We might do that if we were writing commercial software for computer illiterate audience.

Or, we might say, "Tough! The user should know better.""

Or, we just may make it impossible for the user to enter a huge number. This is the approach we will take: We will use an implied 0. prefix.

In other words, if the user wants 0.04, we will expect him to type -p04, or set PINHOLE=04 in his environment. So, if he says -p9999999, we will interpret it as 0.9999999-still ridiculous but at least safer.

Secondly, many users will just want to go with either Bender’ s constant or Connors' constant. To make it easier on them, we will interpret -b as identical to -p04, and -c as identical to -p037.

11.13.3.3. The Output

We need to decide what we want our software to send to the output, and in what format.

Since our input allows for an unspecified number of focal length entries, it makes sense to use a traditional database-style output of showing the result of the calculation for each focal length on a separate line, while separating all values on one line by a tab character.

Optionally, we should also allow the user to specify the use of the CSV format we have studied earlier. In this case, we will print out a line of comma-separated names describing each field of every line, then show our results as before, but substituting a comma for the tab.

We need a command line option for the CSV format. We cannot use -c because that already means use Connors' constant. For some strange reason, many web sites refer to CSV files as "Excel spreadsheet" (though the CSV format predates Excel). We will, therefore, use the -e switch to inform our software we want the output in the CSV format.

We will start each line of the output with the focal length. This may sound repetitious at first, especially in the interactive mode: The user types in the focal length, and we are repeating it.

But the user can type several focal lengths on one line. The input can also come in from a file or from the output of another program. In that case the user does not see the input at all.

By the same token, the output can go to a file which we will want to examine later, or it could go to the printer, or become the input of another program.

So, it makes perfect sense to start each line with the focal length as entered by the user.

No, wait! Not as entered by the user. What if the user types in something like this:

```
00000000150
```

Clearly, we need to strip those leading zeros.

So, we might consider reading the user input as is, converting it to binary inside the FPU, and printing it out from there.

But…

What if the user types something like this:

```
1745976572345235345353453535353053053456350730967676442 3
```

Ha! The packed decimal FPU format lets us input 18-digit numbers. But the user has entered more than 18 digits. How do we handle that?

Well, we could modify our code to read the first 18 digits, enter it to the FPU, then read more, multiply what we already have on the TOS by 10 raised to the number of additional digits, then add to it.

Yes, we could do that. But in this program it would be ridiculous (in a different one it may be just the thing to do): Even the circumference of the Earth expressed in millimeters only takes 11 digits. Clearly, we cannot build a camera that large (not yet, anyway).

So, if the user enters such a huge number, he is either bored, or testing us, or trying to break into the system, or playing games-doing anything but designing a pinhole camera.

What will we do?

We will slap him in the face, in a manner of speaking:

```
1745976572345235345353453535353053053456350730967676442 3  ??? ??? ??? ??? ???
```

To achieve that, we will simply ignore any leading zeros. Once we find a non-zero digit, we will initialize a counter to 0 and start taking three steps:

1. Send the digit to the output.
2. Append the digit to a buffer we will use later to produce the packed decimal we can send to the FPU.
3. Increase the counter.

Now, while we are taking these three steps, we also need to watch out for one of two conditions:

- If the counter grows above 18, we stop appending to the buffer. We continue reading the digits and sending them to the output.
- If, or rather when, the next input character is not a digit, we are done inputting for now.

  Incidentally, we can simply discard the non-digit, unless it is a #, which we must return to the input stream. It starts a comment, so we must see it after we are done producing output and start looking for more input.

That still leaves one possibility uncovered: If all the user enters is a zero (or several zeros), we will never find a non-zero to display.

We can determine this has happened whenever our counter stays at 0. In that case we need to send 0 to the output, and perform another "slap in the face":

```
0  ??? ??? ??? ??? ???
```

Once we have displayed the focal length and determined it is valid (greater than 0 but not exceeding 18 digits), we can calculate the pinhole diameter.

It is not by coincidence that pinhole contains the word pin. Indeed, many a pinhole literally is a pin hole, a hole carefully punched with the tip of a pin.

That is because a typical pinhole is very small. Our formula gets the result in millimeters. We will multiply it by 1000, so we can output the result in microns.

At this point we have yet another trap to face: Too much precision.

Yes, the FPU was designed for high precision mathematics. But we are not dealing with high precision mathematics. We are dealing with physics (optics, specifically).

Suppose we want to convert a truck into a pinhole camera (we would not be the first ones to do that!). Suppose its box is 12 meters long, so we have the focal length of 12000. Well, using Bender' s constant, it gives us square root of 12000 multiplied by 0.04, which is 4.381780460 millimeters, or 4381.780460 microns.

Put either way, the result is absurdly precise. Our truck is not exactly 12000 millimeters long. We did not measure its length with such a precision, so stating we need a pinhole with the diameter of 4.381780460 millimeters is, well, deceiving. 4.4 millimeters would do just fine.

I "only" used ten digits in the above example. Imagine the absurdity of going for all 18!

We need to limit the number of significant digits of our result. One way of doing it is by using an integer representing microns. So, our truck would need a pinhole with the diameter of 4382 microns. Looking at that number, we still decide that 4400 microns, or 4.4 millimeters is close enough.

Additionally, we can decide that no matter how big a result we get, we only want to display four significant digits (or any other number of them, of course). Alas, the FPU does not offer rounding to a specific number of digits (after all, it does not view the numbers as decimal but as binary).

We, therefore, must devise an algorithm to reduce the number of significant digits.

Here is mine (I think it is awkward-if you know a better one, please, let me know):

1. Initialize a counter to 0.
2. While the number is greater than or equal to 10000, divide it by 10 and increase the counter.
3. Output the result.
4. While the counter is greater than 0, output 0 and decrease the counter.

The 10000 is only good if you want four significant digits. For any other number of significant digits, replace 10000 with 10 raised to the number of significant digits.

We will, then, output the pinhole diameter in microns, rounded off to four significant digits.

At this point, we know the focal length and the pinhole diameter. That means we have enough

information to also calculate the f-number.

We will display the f-number, rounded to four significant digits. Chances are the f-number will tell us very little. To make it more meaningful, we can find the nearest normalized f-number, i.e., the nearest power of the square root of 2.

We do that by multiplying the actual f-number by itself, which, of course, will give us its square. We will then calculate its base-2 logarithm, which is much easier to do than calculating the base-square-root-of-2 logarithm! We will round the result to the nearest integer. Next, we will raise 2 to the result. Actually, the FPU gives us a good shortcut to do that: We can use the fscale op code to "scale" 1, which is analogous to shifting an integer left. Finally, we calculate the square root of it all, and we have the nearest normalized f-number.

If all that sounds overwhelming-or too much work, perhaps-it may become much clearer if you see the code. It takes 9 op codes altogether:

```
fmul   st0, st0
  fld1
  fld st1
  fyl2x
  frndint
  fld1
  fscale
  fsqrt
  fstp   st1
```

The first line, fmul st0, st0, squares the contents of the TOS (top of the stack, same as st, called st0 by nasm). The fld1 pushes 1 on the TOS.

The next line, fld st1, pushes the square back to the TOS. At this point the square is both in st and st(2) (it will become clear why we leave a second copy on the stack in a moment). st(1) contains 1.

Next, fyl2x calculates base-2 logarithm of st multiplied by st(1). That is why we placed 1 on st(1) before.

At this point, st contains the logarithm we have just calculated, st(1) contains the square of the actual f-number we saved for later.

frndint rounds the TOS to the nearest integer. fld1 pushes a 1. fscale shifts the 1 we have on the TOS by the value in st(1), effectively raising 2 to st(1).

Finally, fsqrt calculates the square root of the result, i.e., the nearest normalized f-number.

We now have the nearest normalized f-number on the TOS, the base-2 logarithm rounded to the nearest integer in st(1), and the square of the actual f-number in st(2). We are saving the value in st(2) for later.

But we do not need the contents of st(1) anymore. The last line, fstp st1, places the contents of st to st(1), and pops. As a result, what was st(1) is now st, what was st(2) is now st(1), etc. The new st contains the normalized f-number. The new st(1) contains the square of the actual f-number we have stored there for posterity.

At this point, we are ready to output the normalized f-number. Because it is normalized, we will not round it off to four significant digits, but will send it out in its full precision.

The normalized f-number is useful as long as it is reasonably small and can be found on our light meter. Otherwise we need a different method of determining proper exposure.

Earlier we have figured out the formula of calculating proper exposure at an arbitrary f-number from that measured at a different f-number.

Every light meter I have ever seen can determine proper exposure at f5.6. We will, therefore, calculate an "f5.6 multiplier," i.e., by how much we need to multiply the exposure measured at f5.6 to determine the proper exposure for our pinhole camera.

From the above formula we know this factor can be calculated by dividing our f-number (the actual one, not the normalized one) by 5.6, and squaring the result.

Mathematically, dividing the square of our f-number by the square of 5.6 will give us the same result.

Computationally, we do not want to square two numbers when we can only square one. So, the first solution seems better at first.

But…

5.6 is a constant. We do not have to have our FPU waste precious cycles. We can just tell it to divide the square of the f-number by whatever 5.6^2 equals to. Or we can divide the f-number by 5.6, and then square the result. The two ways now seem equal.

But, they are not!

Having studied the principles of photography above, we remember that the 5.6 is actually square root of 2 raised to the fifth power. An irrational number. The square of this number is exactly 32.

Not only is 32 an integer, it is a power of 2. We do not need to divide the square of the f-number by 32. We only need to use fscale to shift it right by five positions. In the FPU lingo it means we will fscale it with st(1) equal to -5. That is much faster than a division.

So, now it has become clear why we have saved the square of the f-number on the top of the FPU stack. The calculation of the f5.6 multiplier is the easiest calculation of this entire program! We will output it rounded to four significant digits.

There is one more useful number we can calculate: The number of stops our f-number is from f5.6. This may help us if our f-number is just outside the range of our light meter, but we have a shutter which lets us set various speeds, and this shutter uses stops.

Say, our f-number is 5 stops from f5.6, and the light meter says we should use 1/1000 sec. Then we can set our shutter speed to 1/1000 first, then move the dial by 5 stops.

This calculation is quite easy as well. All we have to do is to calculate the base-2 logarithm of the f5.6 multiplier we had just calculated (though we need its value from before we rounded it off). We then output the result rounded to the nearest integer. We do not need to worry about having more than four significant digits in this one: The result is most likely to have only one or two digits anyway.

11.13.4. FPU Optimizations

In assembly language we can optimize the FPU code in ways impossible in high languages, including C.

Whenever a C function needs to calculate a floating-point value, it loads all necessary variables and constants into FPU registers. It then does whatever calculation is required to get the correct result. Good C compilers can optimize that part of the code really well.

It "returns" the value by leaving the result on the TOS. However, before it returns, it cleans up. Any variables and constants it used in its calculation are now gone from the FPU.

It cannot do what we just did above: We calculated the square of the f-number and kept it on the stack for later use by another function.

We knew we would need that value later on. We also knew we had enough room on the stack (which only has room for 8 numbers) to store it there.

A C compiler has no way of knowing that a value it has on the stack will be required again in the very near future.

Of course, the C programmer may know it. But the only recourse he has is to store the value in a memory variable.

That means, for one, the value will be changed from the 80-bit precision used internally by the FPU to a C double (64 bits) or even single (32 bits).

That also means that the value must be moved from the TOS into the memory, and then back again. Alas, of all FPU operations, the ones that access the computer memory are the slowest.

So, whenever programming the FPU in assembly language, look for the ways of keeping intermediate results on the FPU stack.

We can take that idea even further! In our program we are using a constant (the one we named PC).

It does not matter how many pinhole diameters we are calculating: 1, 10, 20, 1000, we are always using the same constant. Therefore, we can optimize our program by keeping the constant on the stack all the time.

Early on in our program, we are calculating the value of the above constant. We need to divide our input by 10 for every digit in the constant.

It is much faster to multiply than to divide. So, at the start of our program, we divide 10 into 1 to obtain 0.1, which we then keep on the stack: Instead of dividing the input by 10 for every digit, we multiply it by 0.1.

By the way, we do not input 0.1 directly, even though we could. We have a reason for that: While 0.1 can be expressed with just one decimal place, we do not know how many binary places it takes. We, therefore, let the FPU calculate its binary value to its own high precision.

We are using other constants: We multiply the pinhole diameter by 1000 to convert it from millimeters to microns. We compare numbers to 10000 when we are rounding them off to four significant digits. So, we keep both, 1000 and 10000, on the stack. And, of course, we reuse the 0.1 when rounding off numbers to four digits.

Last but not least, we keep -5 on the stack. We need it to scale the square of the f-number, instead of dividing it by 32. It is not by coincidence we load this constant last. That makes it the top of the stack when only the constants are on it. So, when the square of the f-number is being scaled, the -5 is at st(1), precisely where fscale expects it to be.

It is common to create certain constants from scratch instead of loading them from the memory. That is what we are doing with -5:

```
fld1        ; TOS = 1
fadd   st0, st0   ; TOS = 2
fadd   st0, st0   ; TOS = 4
fld1        ; TOS = 1
faddp  st1, st0   ; TOS = 5
fchs        ; TOS = -5
```

We can generalize all these optimizations into one rule: Keep repeat values on the stack!

PostScript® is a stack-oriented programming language. There are many more

books available about PostScript® than about the FPU assembly language: Mastering PostScript® will help you master the FPU.

11.13.5. pinhole-The Code

```
;;;;;;; pinhole.asm ;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
;
; Find various parameters of a pinhole camera construction and use
;
; Started:   9-Jun-2001
; Updated:  10-Jun-2001
;
; Copyright (c) 2001 G. Adam Stanislav
; All rights reserved.
;
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;

%include    'system.inc'

%define BUFSIZE 2048

section .data
align 4
ten dd  10
thousand    dd  1000
tthou   dd  10000
fd.in   dd  stdin
fd.out  dd  stdout
envar   db  'PINHOLE='  ; Exactly 8 bytes, or 2 dwords long
pinhole db  '04,',      ; Bender's constant (0.04)
connors db  '037', 0Ah  ; Connors' constant
usg db  'Usage: pinhole [-b] [-c] [-e] [-p <value>] [-o <outfile>] [-i <infile>]', 0Ah
usglen  equ $-usg
iemsg   db  "pinhole: Can't open input file", 0Ah
iemlen  equ $-iemsg
oemsg   db  "pinhole: Can't create output file", 0Ah
oemlen  equ $-oemsg
pinmsg  db  "pinhole: The PINHOLE constant must not be 0", 0Ah
pinlen  equ $-pinmsg
toobig  db  "pinhole: The PINHOLE constant may not exceed 18 decimal places", 0Ah
biglen  equ $-toobig
huhmsg  db  9, '???'
separ   db  9, '???'
```

```
sep2   db  9, '???'
sep3   db  9, '???'
sep4   db  9, '???', 0Ah
huhlen  equ $-huhmsg
header  db  'focal length in millimeters,pinhole diameter in microns,'
   db  'F-number,normalized F-number,F-5.6 multiplier,stops '
   db  'from F-5.6', 0Ah
headlen equ $-header

section .bss
ibuffer resb   BUFSIZE
obuffer resb   BUFSIZE
dbuffer resb   20     ; decimal input buffer
bbuffer resb   10     ; BCD buffer

section .text
align 4
huh:
   call   write
   push   dword huhlen
   push   dword huhmsg
   push   dword [fd.out]
   sys.write
   add esp, byte 12
   ret

align 4
perr:
   push   dword pinlen
   push   dword pinmsg
   push   dword stderr
   sys.write
   push   dword 4    ; return failure
   sys.exit

align 4
consttoobig:
   push   dword biglen
   push   dword toobig
   push   dword stderr
   sys.write
   push   dword 5    ; return failure
```

```
    sys.exit

align 4
ierr:
    push    dword iemlen
    push    dword iemsg
    push    dword stderr
    sys.write
    push    dword 1     ; return failure
    sys.exit

align 4
oerr:
    push    dword oemlen
    push    dword oemsg
    push    dword stderr
    sys.write
    push    dword 2
    sys.exit

align 4
usage:
    push    dword usglen
    push    dword usg
    push    dword stderr
    sys.write
    push    dword 3
    sys.exit

align 4
global  _start
_start:
    add esp, byte 8 ; discard argc and argv[0]
    sub esi, esi

.arg:
    pop ecx
    or  ecx, ecx
    je  near .getenv       ; no more arguments

    ; ECX contains the pointer to an argument
    cmp byte [ecx], '-'
```

```
    jne usage

    inc ecx
    mov ax, [ecx]
    inc ecx

.o:
    cmp al, 'o'
    jne .i

    ; Make sure we are not asked for the output file twice
    cmp dword [fd.out], stdout
    jne usage

    ; Find the path to output file - it is either at [ECX+1],
    ; i.e., -ofile --
    ; or in the next argument,
    ; i.e., -o file

    or  ah, ah
    jne .openoutput
    pop ecx
    jecxz   usage

.openoutput:
    push    dword 420   ; file mode (644 octal)
    push    dword 0200h | 0400h | 01h
    ; O_CREAT | O_TRUNC | O_WRONLY
    push    ecx
    sys.open
    jc  near oerr

    add esp, byte 12
    mov [fd.out], eax
    jmp short .arg

.i:
    cmp al, 'i'
    jne .p

    ; Make sure we are not asked twice
    cmp dword [fd.in], stdin
```

```
    jne near usage

    ; Find the path to the input file
    or  ah, ah
    jne .openinput
    pop ecx
    or  ecx, ecx
    je near usage

.openinput:
    push    dword 0    ; O_RDONLY
    push    ecx
    sys.open
    jc  near ierr      ; open failed

    add esp, byte 8
    mov [fd.in], eax
    jmp .arg

.p:
    cmp al, 'p'
    jne .c
    or  ah, ah
    jne .pcheck

    pop ecx
    or  ecx, ecx
    je  near usage

    mov ah, [ecx]

.pcheck:
    cmp ah, '0'
    jl  near usage
    cmp ah, '9'
    ja  near usage
    mov esi, ecx
    jmp .arg

.c:
    cmp al, 'c'
    jne .b
```

```
    or  ah, ah
    jne near usage
    mov esi, connors
    jmp .arg

.b:
    cmp al, 'b'
    jne .e
    or  ah, ah
    jne near usage
    mov esi, pinhole
    jmp .arg

.e:
    cmp al, 'e'
    jne near usage
    or  ah, ah
    jne near usage
    mov al, ','
    mov [huhmsg], al
    mov [separ], al
    mov [sep2], al
    mov [sep3], al
    mov [sep4], al
    jmp .arg

align 4
.getenv:
    ; If ESI = 0, we did not have a -p argument,
    ; and need to check the environment for "PINHOLE="
    or  esi, esi
    jne .init

    sub ecx, ecx

.nextenv:
    pop esi
    or  esi, esi
    je  .default    ; no PINHOLE envar found

    ; check if this envar starts with 'PINHOLE='
    mov edi, envar
```

```
    mov cl, 2      ; 'PINHOLE=' is 2 dwords long
rep cmpsd
    jne .nextenv

    ; Check if it is followed by a digit
    mov al, [esi]
    cmp al, '0'
    jl  .default
    cmp al, '9'
    jbe .init
    ; fall through

align 4
.default:
    ; We got here because we had no -p argument,
    ; and did not find the PINHOLE envar.
    mov esi, pinhole
    ; fall through

align 4
.init:
    sub eax, eax
    sub ebx, ebx
    sub ecx, ecx
    sub edx, edx
    mov edi, dbuffer+1
    mov byte [dbuffer], '0'

    ; Convert the pinhole constant to real
.constloop:
    lodsb
    cmp al, '9'
    ja  .setconst
    cmp al, '0'
    je  .processconst
    jb  .setconst

    inc dl

.processconst:
    inc cl
    cmp cl, 18
```

```
    ja  near consttoobig
    stosb
    jmp short .constloop

align 4
.setconst:
    or  dl, dl
    je  near perr

    finit
    fild    dword [tthou]

    fld1
    fild    dword [ten]
    fdivp   st1, st0

    fild    dword [thousand]
    mov edi, obuffer

    mov ebp, ecx
    call    bcdload

.constdiv:
    fmul    st0, st2
    loop    .constdiv

    fld1
    fadd    st0, st0
    fadd    st0, st0
    fld1
    faddp   st1, st0
    fchs

    ; If we are creating a CSV file,
    ; print header
    cmp byte [separ], ','
    jne .bigloop

    push    dword headlen
    push    dword header
    push    dword [fd.out]
    sys.write
```

```
.bigloop:
   call   getchar
   jc  near done

   ; Skip to the end of the line if you got '#'
   cmp al, '#'
   jne .num
   call   skiptoeol
   jmp short .bigloop

.num:
   ; See if you got a number
   cmp al, '0'
   jl  .bigloop
   cmp al, '9'
   ja  .bigloop

   ; Yes, we have a number
   sub ebp, ebp
   sub edx, edx

.number:
   cmp al, '0'
   je  .number0
   mov dl, 1

.number0:
   or  dl, dl     ; Skip leading 0's
   je  .nextnumber
   push   eax
   call   putchar
   pop eax
   inc ebp
   cmp ebp, 19
   jae .nextnumber
   mov [dbuffer+ebp], al

.nextnumber:
   call   getchar
   jc  .work
   cmp al, '#'
```

```
    je  .ungetc
    cmp al, '0'
    jl  .work
    cmp al, '9'
    ja  .work
    jmp short .number

.ungetc:
    dec esi
    inc ebx

.work:
    ; Now, do all the work
    or  dl, dl
    je  near .work0

    cmp ebp, 19
    jae near .toobig

    call    bcdload

    ; Calculate pinhole diameter

    fld st0 ; save it
    fsqrt
    fmul    st0, st3
    fld st0
    fmul    st5
    sub ebp, ebp

    ; Round off to 4 significant digits
.diameter:
    fcom    st0, st7
    fstsw   ax
    sahf
    jb  .printdiameter
    fmul    st0, st6
    inc ebp
    jmp short .diameter

.printdiameter:
    call    printnumber ; pinhole diameter
```

```
    ; Calculate F-number

    fdivp   st1, st0
    fld st0

    sub ebp, ebp

.fnumber:
    fcom    st0, st6
    fstsw   ax
    sahf
    jb  .printfnumber
    fmul    st0, st5
    inc ebp
    jmp short .fnumber

.printfnumber:
    call    printnumber ; F number

    ; Calculate normalized F-number
    fmul    st0, st0
    fld1
    fld st1
    fyl2x
    frndint
    fld1
    fscale
    fsqrt
    fstp    st1

    sub ebp, ebp
    call    printnumber

    ; Calculate time multiplier from F-5.6

    fscale
    fld st0

    ; Round off to 4 significant digits
.fmul:
    fcom    st0, st6
```

```
    fstsw   ax
    sahf

    jb  .printfmul
    inc ebp
    fmul    st0, st5
    jmp short .fmul

.printfmul:
    call    printnumber ; F multiplier

    ; Calculate F-stops from 5.6

    fld1
    fxch    st1
    fyl2x

    sub ebp, ebp
    call    printnumber

    mov al, 0Ah
    call    putchar
    jmp .bigloop

.work0:
    mov al, '0'
    call    putchar

align 4
.toobig:
    call    huh
    jmp .bigloop

align 4
done:
    call    write       ; flush output buffer

    ; close files
    push    dword [fd.in]
    sys.close

    push    dword [fd.out]
```

```
    sys.close

    finit

    ; return success
    push    dword 0
    sys.exit

align 4
skiptoeol:
    ; Keep reading until you come to cr, lf, or eof
    call    getchar
    jc  done
    cmp al, 0Ah
    jne .cr
    ret

.cr:
    cmp al, 0Dh
    jne skiptoeol
    ret

align 4
getchar:
    or  ebx, ebx
    jne .fetch

    call    read

.fetch:
    lodsb
    dec ebx
    clc
    ret

read:
    jecxz   .read
    call    write

.read:
    push    dword BUFSIZE
    mov esi, ibuffer
```

```
    push    esi
    push    dword [fd.in]
    sys.read
    add esp, byte 12
    mov ebx, eax
    or  eax, eax
    je  .empty
    sub eax, eax
    ret

align 4
.empty:
    add esp, byte 4
    stc
    ret

align 4
putchar:
    stosb
    inc ecx
    cmp ecx, BUFSIZE
    je  write
    ret

align 4
write:
    jecxz   .ret    ; nothing to write
    sub edi, ecx    ; start of buffer
    push    ecx
    push    edi
    push    dword [fd.out]
    sys.write
    add esp, byte 12
    sub eax, eax
    sub ecx, ecx    ; buffer is empty now
.ret:
    ret

align 4
bcdload:
    ; EBP contains the number of chars in dbuffer
    push    ecx
```

```
    push   esi
    push   edi

    lea ecx, [ebp+1]
    lea esi, [dbuffer+ebp-1]
    shr ecx, 1

    std

    mov edi, bbuffer
    sub eax, eax
    mov [edi], eax
    mov [edi+4], eax
    mov [edi+2], ax

.loop:
    lodsw
    sub ax, 3030h
    shl al, 4
    or  al, ah
    mov [edi], al
    inc edi
    loop   .loop

    fbld   [bbuffer]

    cld
    pop edi
    pop esi
    pop ecx
    sub eax, eax
    ret

align 4
printnumber:
    push   ebp
    mov al, [separ]
    call   putchar

    ; Print the integer at the TOS
    mov ebp, bbuffer+9
    fbstp  [bbuffer]
```

```
    ; Check the sign
    mov al, [ebp]
    dec ebp
    or  al, al
    jns .leading

    ; We got a negative number (should never happen)
    mov al, '-'
    call    putchar

.leading:
    ; Skip leading zeros
    mov al, [ebp]
    dec ebp
    or  al, al
    jne .first
    cmp ebp, bbuffer
    jae .leading

    ; We are here because the result was 0.
    ; Print '0' and return
    mov al, '0'
    jmp putchar

.first:
    ; We have found the first non-zero.
    ; But it is still packed
    test    al, 0F0h
    jz  .second
    push    eax
    shr al, 4
    add al, '0'
    call    putchar
    pop eax
    and al, 0Fh

.second:
    add al, '0'
    call    putchar

.next:
```

```
    cmp ebp, bbuffer
    jb  .done

    mov al, [ebp]
    push    eax
    shr al, 4
    add al, '0'
    call    putchar
    pop eax
    and al, 0Fh
    add al, '0'
    call    putchar

    dec ebp
    jmp short .next

.done:
    pop ebp
    or  ebp, ebp
    je  .ret

.zeros:
    mov al, '0'
    call    putchar
    dec ebp
    jne .zeros

.ret:
    ret
```

The code follows the same format as all the other filters we have seen before, with one subtle exception:

> We are no longer assuming that the end of input implies the end of things to do, something we took for granted in the character-oriented filters.
>
> This filter does not process characters. It processes a language (albeit a very simple one, consisting only of numbers).
>
> When we have no more input, it can mean one of two things:
>
> - We are done and can quit. This is the same as before.
> - The last character we have read was a digit. We have stored it at the end of our ASCII-to-float conversion buffer. We now need to convert the contents of that buffer into a number and write the last line of our

> output.
>
> For that reason, we have modified our getchar and our read routines to return with the carry flag clear whenever we are fetching another character from the input, or the carry flag set whenever there is no more input.
>
> Of course, we are still using assembly language magic to do that! Take a good look at getchar. It always returns with the carry flag clear.
>
> Yet, our main code relies on the carry flag to tell it when to quit-and it works.
>
> The magic is in read. Whenever it receives more input from the system, it just returns to getchar, which fetches a character from the input buffer, clears the carry flag and returns.
>
> But when read receives no more input from the system, it does not return to getchar at all. Instead, the add esp, byte 4 op code adds 4 to ESP, sets the carry flag, and returns.
>
> So, where does it return to? Whenever a program uses the call op code, the microprocessor pushes the return address, i.e., it stores it on the top of the stack (not the FPU stack, the system stack, which is in the memory). When a program uses the ret op code, the microprocessor pops the return value from the stack, and jumps to the address that was stored there.
>
> But since we added 4 to ESP (which is the stack pointer register), we have effectively given the microprocessor a minor case of amnesia: It no longer remembers it was getchar that called read.
>
> And since getchar never pushed anything before calling read, the top of the stack now contains the return address to whatever or whoever called getchar. As far as that caller is concerned, he called getchar, which returned with the carry flag set!

Other than that, the bcdload routine is caught up in the middle of a Lilliputian conflict between the Big-Endians and the Little-Endians.

It is converting the text representation of a number into that number: The text is stored in the big-endian order, but the packed decimal is little-endian.

To solve the conflict, we use the std op code early on. We cancel it with cld later on: It is quite important we do not call anything that may depend on the default setting of the direction flag while std is active.

Everything else in this code should be quit eclear, providing you have read the entire chapter that precedes it.

It is a classical example of the adage that programming requires a lot of thought and only a little coding. Once we have thought through every tiny detail, the code almost writes itself.

11.13.6. Using pinhole

Because we have decided to make the program ignore any input except for numbers (and even those inside a comment), we can actually perform textual queries. We do not have to, but we can.

In my humble opinion, forming a textual query, instead of having to follow a very strict syntax, makes software much more user friendly.

Suppose we want to build a pinhole camera to use the 4x5 inch film. The standard focal length for that film is about 150mm. We want to fine-tune our focal length so the pinhole diameter is as round a number as possible. Let us also suppose we are quite comfortable with cameras but somewhat intimidated by computers. Rather than just have to type in a bunch of numbers, we want to ask a couple of questions.

Our session might look like this:

```
% pinhole

Computer,

What size pinhole do I need for the focal length of 150?
150 490 306 362 2930   12
Hmmm... How about 160?
160 506 316 362 3125   12
Let's make it 155, please.
155 498 311 362 3027   12
Ah, let's try 157...
157 501 313 362 3066   12
156?
156 500 312 362 3047   12
That's it! Perfect! Thank you very much!
^D
```

We have found that while for the focal length of 150, our pinhole diameter should be 490 microns, or 0.49 mm, if we go with the almost identical focal length of 156 mm, we can get away with a pinhole diameter of exactly one half of a millimeter.

11.13.7. Scripting

Because we have chosen the # character to denote the start of a comment, we can treat our pinhole software as a scripting language.

You have probably seen shell scripts that start with:

```
#! /bin/sh
```

⋯or⋯

```
#!/bin/sh
```

⋯because the blank space after the #! is optional.

Whenever UNIX® is asked to run an executable file which starts with the #!, it assumes the file is a script. It adds the command to the rest of the first line of the script, and tries to execute that.

Suppose now that we have installed pinhole in /usr/local/bin/, we can now write a script to calculate various pinhole diameters suitable for various focal lengths commonly used with the 120 film.

The script might look something like this:

```
#! /usr/local/bin/pinhole -b -i
# Find the best pinhole diameter
# for the 120 film

### Standard
80

### Wide angle
30, 40, 50, 60, 70

### Telephoto
100, 120, 140
```

Because 120 is a medium size film, we may name this file medium.

We can set its permissions to execute, and run it as if it were a program:

```
% chmod 755 medium
% ./medium
```

UNIX® will interpret that last command as:

```
% /usr/local/bin/pinhole -b -i ./medium
```

It will run that command and display:

```
80  358 224 256 1562   11
30  219 137 128 586 9
40  253 158 181 781 10
50  283 177 181 977 10
60  310 194 181 1172   10
70  335 209 181 1367   10
100 400 250 256 1953   11
120 438 274 256 2344   11
140 473 296 256 2734   11
```

Now, let us enter:

```
% ./medium -c
```

UNIX® will treat that as:

```
% /usr/local/bin/pinhole -b -i ./medium -c
```

That gives it two conflicting options: -b and -c (Use Bender’ s constant and use Connors' constant). We have programmed it so later options override early ones-our program will calculate everything using Connors' constant:

```
80  331 242 256 1826    11
30  203 148 128 685 9
40  234 171 181 913 10
50  262 191 181 1141    10
60  287 209 181 1370    10
70  310 226 256 1598    11
100 370 270 256 2283    11
120 405 296 256 2739    11
140 438 320 362 3196    12
```

We decide we want to go with Bender’ s constant after all. We want to save its values as a comma-separated file:

```
% ./medium -b -e > bender
% cat bender
focal length in millimeters,pinhole diameter in microns,F-number,normalized F-number,F-
5.6 multiplier,stops from F-5.6
80,358,224,256,1562,11
30,219,137,128,586,9
40,253,158,181,781,10
50,283,177,181,977,10
60,310,194,181,1172,10
70,335,209,181,1367,10
100,400,250,256,1953,11
120,438,274,256,2344,11
140,473,296,256,2734,11
%
```

11.14. Caveats

Assembly language programmers who "grew up" under MS-DOS® and Windows® often tend to take shortcuts. Reading the keyboard scan codes and writing directly to video memory are two classical examples of practices which, under MS-DOS® are not frowned upon but considered the right thing to do.

The reason? Both the PC BIOS and MS-DOS® are notoriously slow when performing these operations.

You may be tempted to continue similar practices in the UNIX® environment. For example, I have seen a web site which explains how to access the keyboard scan codes on a popular UNIX® clone.

That is generally a very bad idea in UNIX® environment! Let me explain why.

11.14.1. UNIX® Is Protected

For one thing, it may simply not be possible. UNIX® runs in protected mode. Only the kernel and device drivers are allowed to access hardware directly. Perhaps a particular UNIX® clone will let you read the keyboard scan codes, but chances are a real UNIX® operating system will not. And even if one version may let you do it, the next one may not, so your carefully crafted software may become a dinosaur overnight.

11.14.2. UNIX® Is an Abstraction

But there is a much more important reason not to try accessing the hardware directly (unless, of course, you are writing a device driver), even on the UNIX® like systems that let you do it:

UNIX® is an abstraction!

There is a major difference in the philosophy of design between MS-DOS® and UNIX®. MS-DOS® was designed as a single-user system. It is run on a computer with a keyboard and a video screen attached directly to that computer. User input is almost guaranteed to come from that keyboard. Your program's output virtually always ends up on that screen.

This is NEVER guaranteed under UNIX®. It is quite common for a UNIX® user to pipe and redirect program input and output:

```
% program1 | program2 | program3 > file1
```

If you have written program2, your input does not come from the keyboard but from the output of program1. Similarly, your output does not go to the screen but becomes the input for program3 whose output, in turn, goes to file1.

But there is more! Even if you made sure that your input comes from, and your output goes to, the terminal, there is no guarantee the terminal is a PC: It may not have its video memory where you expect it, nor may its keyboard be producing PC-style scan codes. It may be a Macintosh®, or any other computer.

Now you may be shaking your head: My software is in PC assembly language, how can it run on a Macintosh®? But I did not say your software would be running on a Macintosh®, only that its terminal may be a Macintosh®.

Under UNIX®, the terminal does not have to be directly attached to the computer that runs your software, it can even be on another continent, or, for that matter, on another planet. It is perfectly possible that a Macintosh® user in Australia connects to a UNIX® system in North America (or anywhere else) via telnet. The software then runs on one computer, while the terminal is on a different computer: If you try to read the scan codes, you will get the wrong input!

Same holds true about any other hardware: A file you are reading may be on a disk you have no direct access to. A camera you are reading images from may be on a space shuttle, connected to you via satellites.

That is why under UNIX® you must never make any assumptions about where your data is coming from and going to. Always let the system handle the physical access to the hardware.

These are caveats, not absolute rules. Exceptions are possible. For example, if a

text editor has determined it is running on a local machine, it may want to read the scan codes directly for improved control. I am not mentioning these caveats to tell you what to do or what not to do, just to make you aware of certain pitfalls that await you if you have just arrived to UNIX® form MS-DOS®. Of course, creative people often break rules, and it is OK as long as they know they are breaking them and why.

11.15. Acknowledgements

This tutorial would never have been possible without the help of many experienced FreeBSD programmers from the FreeBSD technical discussions 郵遞論壇, many of whom have patiently answered my questions, and pointed me in the right direction in my attempts to explore the inner workings of UNIX® system programming in general and FreeBSD in particular.

Thomas M. Sommers opened the door for me . His How do I write "Hello, world" in FreeBSD assembler? web page was my first encounter with an example of assembly language programming under FreeBSD.

Jake Burkholder has kept the door open by willingly answering all of my questions and supplying me with example assembly language source code.

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Part V: Appendices

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