Developing Embedded Software with Free and Open Source Tools

or

How Free is Free?

Mark S. VanderVoord

Why Listen to the 6'3” Geek?

- 10 years of Embedded Software Experience
- Autonomous Vehicle
  - 18 micro's / dsp's
  - Safety Critical
  - Almost completely developed using Free or Open Source

What is This FOSS Thing?

Free Software

"Free" as in "Free Speech" not "Free Beer"

0. Run For Any Reason
1. Study and Adapt
2. Redistribute
3. Improve & Share

Open Source

1. Free Distribution
2. Source Code
3. Derived Works
4. Integrity of Author
5. No Discrimination
6. Restriction Free License

What is Your FOSS Quotient?

Linux

Apache

BSD

Gnome

KDE

Eclipse

Mozilla / Firefox

MySQL

OpenOffice.org

CVS

GCC

Perl

Python

Open Cyc

GIMP

Audacity

Bit Torrent

Ruby

VNC

7zip

Blender

MythTV

GAIM

Mono

24 projects... 131,255 listed on sourceforge.net

Why Free / Open Source?
Reasons for Developers

You can see all the code! (debug)

More maintainable

"More eyes"

Customizable

Richer Feature Set

Pride / Giving back to Community

Why Free / Open Source?
Reasons for Management

- No Vendor Lock-in
- Tools Scale with Team
- No service / upgrade fees
- No Run-Time Licenses
- No Danger of Abandonment of Legacy Systems

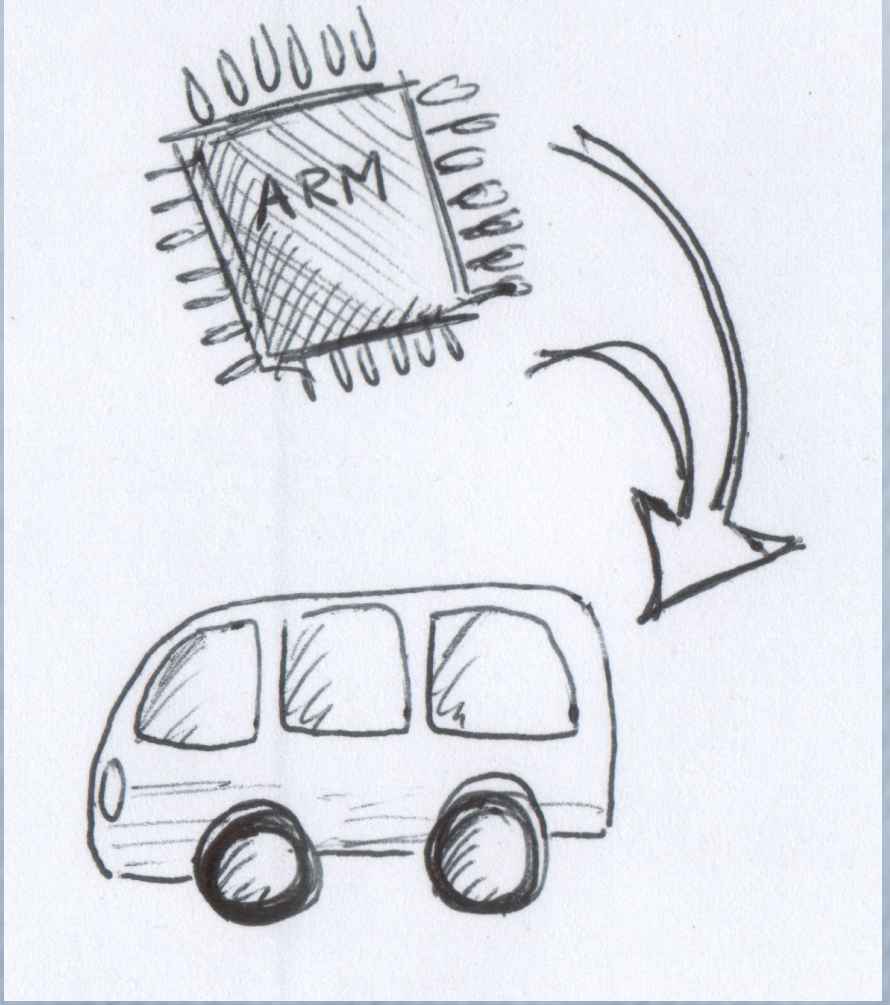
Why Not Free / Open Source?

- Time investment to learn and configure
- Support is more challenging to find
- Inaccurate project status indicators
- Poor documentation
- Inability to fulfill license obligations
  - GPL
  - LGPL
  - MIT

What's Up With Embedded?

What Makes it Unique?

- Memory Constraints (RAM, Storage)
- CPU Constraints
- Debug Challenges
- Coupling with Hardware
- Interaction with Real-Time Events



What is Your Embedded FOSS Quotient?

GX-Linux

Monta Vista Linux

RTEMS

eCos

wxWindows

newlib

uClibC++

MicroMonitor

RedBoot

FreeRTOS

protoThreads

GTK Embedded

QT Embedded

Embedded C++

GNAT

SQLLite

GDB remoting

mips-rtems-gcc

ppc-ecos-g++

Armulator

H8sim

psim

or32*

The Mighty Compiler
GCC

GNU Compiler Collection

C, C++, Objective C, Ada, D, Java

MIPS, ARM, x86, PowerPC, SuperH, Coldfire, Xscale, HC11, 68000, AVR, Mcore, Alpha, Sparc...

Configurable to Different Standards:

ANSI (by release)

Embedded C++

GCC extensions

Closed Competition:

Metrowerks, IAR, Cosmic, Keil, etc.

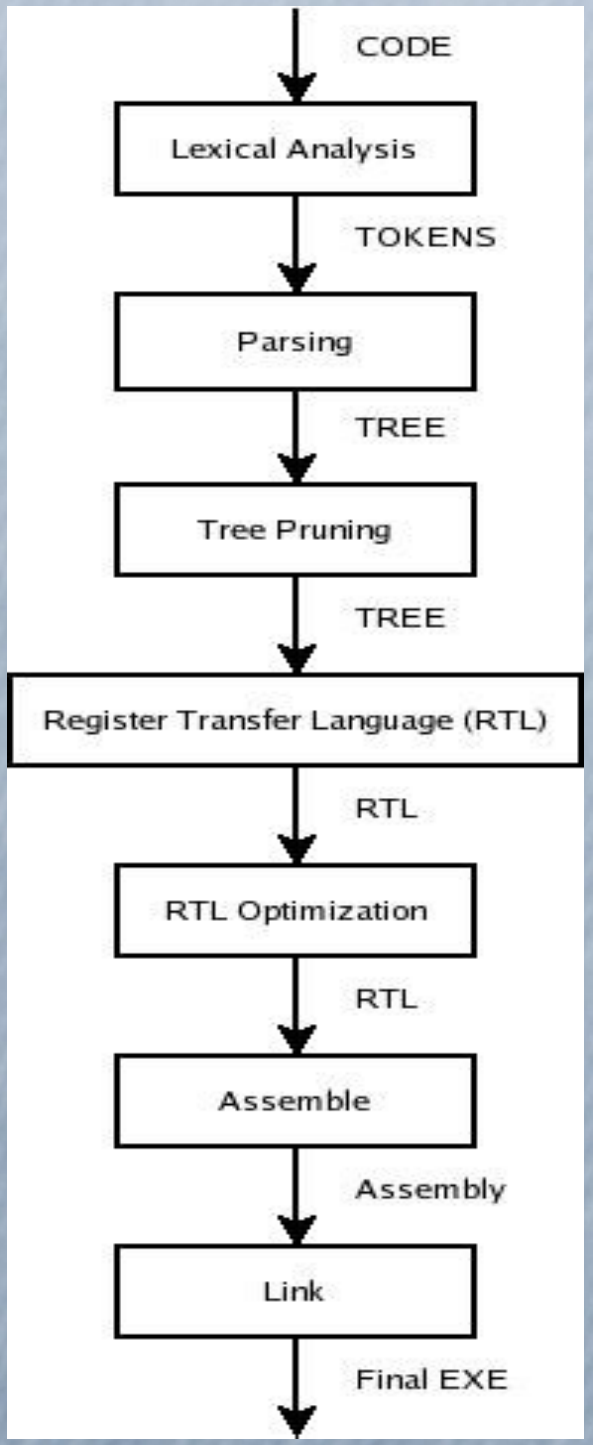
The Mighty Compiler
GCC : C Extensions

Borrowed from C++

- Anonymous unions
- Function inlining
  - Option to force
- 64 bit integers
- Late type declaration
- Strong type checking

Unique

- Data alignment
- Data packing
- Variable / zero length arrays
- Section and Anchors
- typeof( )
- Access to return addresses & stack frame pointer



The Mighty Compiler

GCC : How it works

Front-End

- Lexical Analysis
- Parsing

Core

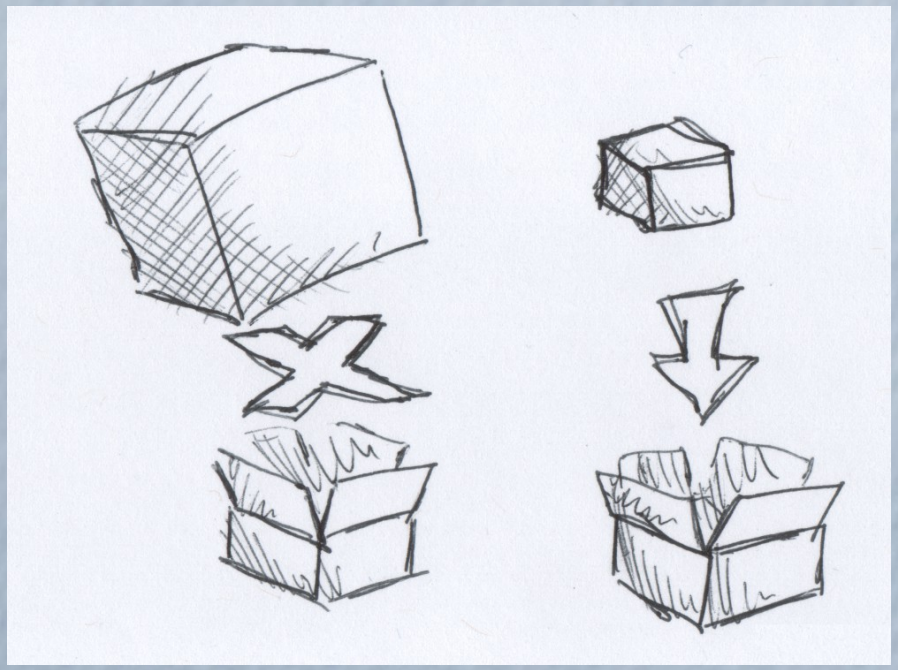
- Tree Pruning
- RTL & Optimization

Back-End

- Assemble & Link

“Not So” Standard Libraries
Newlib, uClibc++

- “Standard” Standard Libraries for C / C++
  - Large Footprint
  - Assume Doubles
  - Assume Lots of RAM or Virtual Mem
  - Do-It-All Functions like printf
  - Unsafe Functions



“Not So” Standard Libraries

Newlib

Std C Lib

- Memory handling
- Integer math
- Casting operators
- IO and strings
- All Reentrant
- Lightweight
  - iprintf (integer-only)
  - putc (macro)

Math Lib

- Software / Hardware floating point
- Reentrant
- Four Versions:
  - IEEE, POSIX, X/Open, SVID
- fastmath options
- single precision options

“Not So” Standard Libraries
uClibC++

- Supports full C, C++ or Embedded C++
- Optimized for size over speed
- Light Function Alternatives

Embedded C++

- No Exceptions
- No Multiple Inheritance
- No Run-Time Type Checking
- No Pure Virtual
- No Templates

Getting Everything Rolling
MicroMonitor, RedBoot

Bootloader Goals

- Reliable System-Startup
- Power-Safe Upgrades
- Debug Assistance
- Low Overhead
- Cross Platform

Getting Everything Rolling
MicroMonitor

- Cross-Platform
  - ARM, ColdFire, MIPS, PowerPC, StrongARM, SuperH, XScale, X86
- UDP/IP or Serial
- TFTP, Xmodem
- Command Line Interface
- Tiny File System
  - Script Files
  - Exec Bin or Elf
  - Auto-Start Option
  - In-Place Modifiable Data Files
  - Single Directory
- GDB Stubs

Getting Everything Rolling
RedBoot

- Cross-Platform
  - ARM, CalmRISC, ColdFire, MIPS, PowerPC, SPARC, StrongARM, XScale, X86
- TCP/IP or Serial
- TFTP, Xmodem, Ymodem
- Boot From
  - Flash
  - TFTP Server
- Command Line Interface
- Flash Image System
  - Exec or Data blocks

Can I Get an OS With That?
Embedded Linux

Blue Cat Linux

GX-Linux

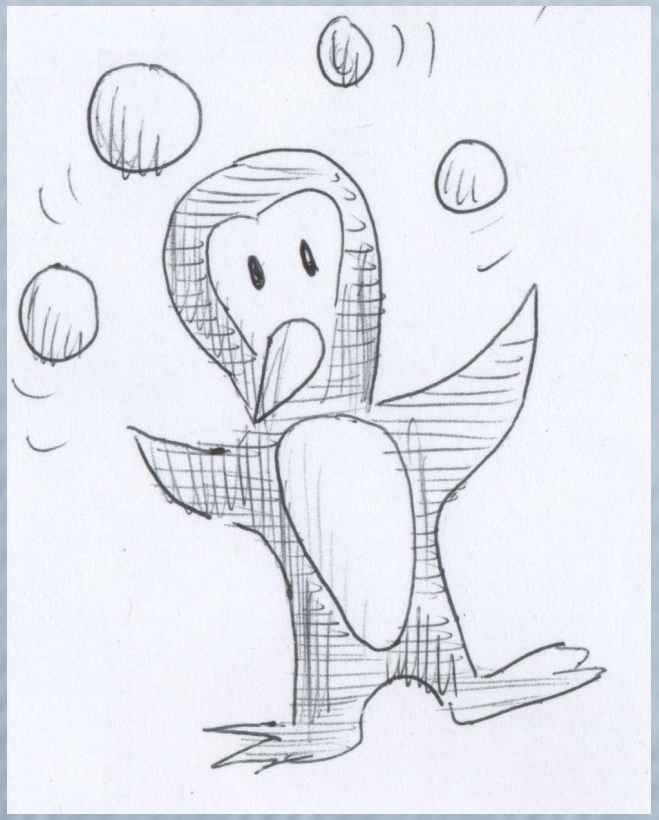
Monta Vista Linux

RT-Linux

Timesys LinuxLink

uCLinux

WindRiver CG Linux



Closed Competition:

Windows CE

I Meant a "Real" Embedded OS
RTEMS, eCos

RTOS Goals:

- Determinism
- Failsafe
- Extensible Driver / Hardware Support
- Guarantee Task Schedules
- Provide Flexible Synchronization Methods

Closed Competition:

VxWorks, QNX, MicroC/OS-II, OSE, OS-9, TRON

I Meant a "Real" Embedded OS
RTEMS

Real-Time Executive for Multiprocessor Systems

Hard Real-Time

Native, POSIX, and TRON modes

C, C++, Ada API's

Many Target CPU's

Kernel Features:

- Deadline (Rate-Monotonic) Scheduler
- Priority Preemptive Task Scheduler
- Priority Inheritance
- Homogeneous & Heterogeneous Multi-Processor Systems
- Interrupt Management

I Meant a "Real" Embedded OS
RTEMS

- Synchronization
  - Dual Port Memory
  - Events
  - Message Queues
  - Semaphores
  - Signals
- Multi-Processor supports can be transparent

- Drivers
  - TCP/IP, DHCP, UDP/IP, TTFTP
  - Serial, I2C, SPI, UART
  - CAN
  - Timers, Clocks
  - Partition / Region Memory Managers
  - Debug CLI & API

I Meant a “Real” Embedded OS

eCos

- embedded Configurable OS
- GUI Config Tool
- Hard Real-Time
- Native, POSIX, and TRON modes
- C API
- Many Target CPU's

Kernel Features:

- 3 scheduler options:
  - None
  - Bitmap
  - Multi-Level Queue
- Priority Preemptive Task Scheduler
- Symmetric Multi-Processing Support
- Interrupt Management

I Meant a “Real” Embedded OS

eCos

Synchronization

- Condition Variables
- Events
- Mailboxes
- Mutexes
- Semaphores

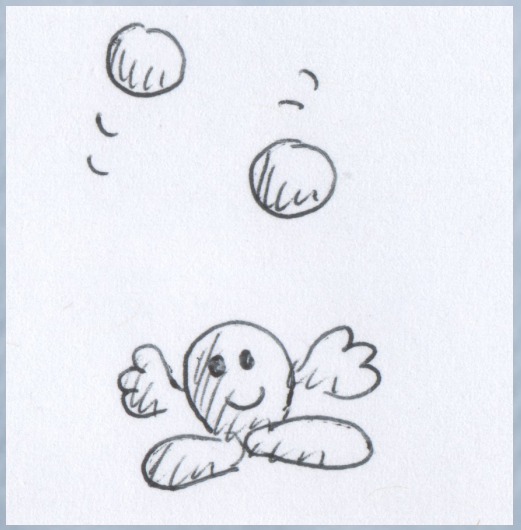
Drivers

- TCP/IP, DHCP, UDP/IP, TTFTP, HTTP Server
- Serial, I2C, SPI, UART
- USB
- Timers, Clocks, Alarms
- Heap Memory Manager
- Debug API

I Mean, This Micro is Small
FreeRTOS, proto-threads

Mini-RTOS Goals:

- Multi-tasking
- Simple Synchronization
- Low Memory Overhead
- Low Latency
- Low Footprint



Closed Competition:

ImageCraft uexec

I Mean, This Micro is Small
FreeRTOS

Two Scheduler Options:

- Preemptive priority scheduler with Round Robin Time-Slicing
- Cooperative

Message Queues

Semaphore Macros

Co-Routines

- Macros create task-like interface
- All co-routines run in same task
- Internal state machine hidden from developer
- Stack usage restrictions
- No Priorities

I Mean, This Micro is Small

proto-threads

- Full system built on Co-Routines
- Simple macro-based interface
- Cooperative multitasking
- Semaphores
- Events
- Extremely low RAM usage
- Low Latency

"A computer is a state machine. Threads are for people who can't program state machines."

Alan Cox

I Mean, This Micro is Small
home-grown sync objects

Mutex

- Atomic Read/Write Instruction
- Release by writing 1, Claim by Subtracting 1 & Check Zero Flag
- Release by writing 1, Claim by Shift Right & Check Carry Flag

Semaphore

- Atomic Read/Write Instruction
- Initialize to (1 << max_count), use shift and carry flag to claim and release the semaphore

Even Embedded Developers Need a Debugger Now and Then

- GNU Debugger (GDB)
  - Breakpoints
    - Hardware / software
    - Conditional
    - Counting
  - Tracepoints
  - Call / Data Stack Analyzer
  - Watches
- Inspect / Evaluate
- Scriptable
- Multiple Targets
- Remote Debugging
- Stubs already in most FOSS Operating Systems, Boot Monitors, etc.

Form and Function
Eclipse CDT

"Not all of us can be as hardcore as emacs or vi users"

Eclipse

- Cross Platform
- Extensible Plug-In Architecture

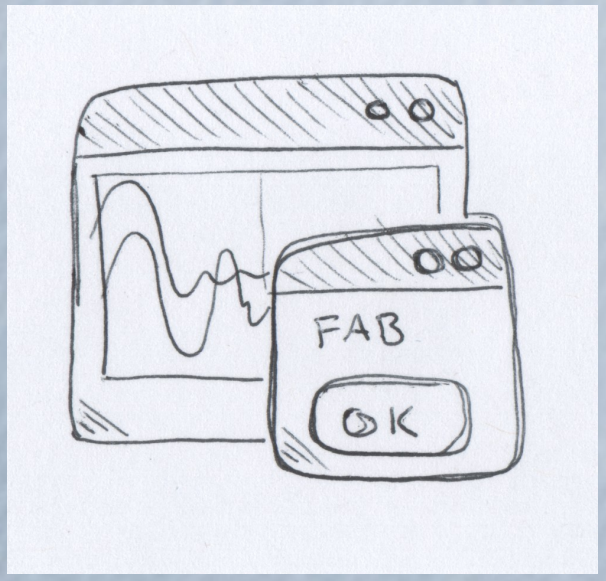
C/C++ Devel Kit

- Syntax Highlighting
- Build Manager
- Todo Manager
- Declaration Linking
- Regular Expressions
- Debug Interface
- Remote Tools

GUI Goodness
Qtopia Core

GUI Toolbox Goals:

- Lightweight
- Cross-platform
- Support varying color depths, resolutions, and profiles
- Full Widget Set
- Custom Fonts & Language Support



Closed Competition:

- Swellsoft PEG
- QNX Photon
- Mentor Nucleus

GUI Goodness

Qtopia Core

- Embedded version of QT toolkit
- Dual Licensed
- Memory mapped frame buffer
- C / C++
- Copy on Write
- Compression
- QT Pre-Rendered Fonts (QPF), TTF, PS1, BDF
- Skinnable Interface
- Customizable drivers for display, keyboard, mouse, and touch screen

GUI Goodness

Qtopia Core

- Windows
- Panes
- Buttons
- Text, spin, combo, check, option, and password boxes
- Sliders
- List, tree, map views
- Tables & grids
- Splitters
- Docks
- Toolbars
- Scroll zones
- Line, curve, shape, and shape drawing
- Layout engine

It's All About the Math

C / C++

Fixed Point

Rational Numbers

Complex Numbers

Vectors

Matrices

Variable-Precision Angle Types

Places to Look:

- Source Forge
- Boost Libraries
- Code Guru
- Embedded.com

Strings, Text, and Expressions

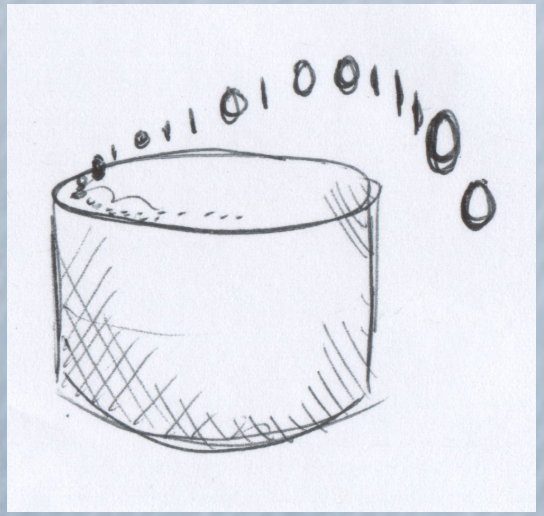
- Copy On Write
- Safe
  - Buffer Overrun protection
  - Support inline nulls
  - Fast Len, Concat, etc.
- Transparent use of constant strings

- Places to Look:
  - Source Forge
  - Boost Libraries
- Recommendations:
  - Better String Lib (bstring) C
  - Embedded Strings (E_STR) C++

Embedded Databases
BerkeleyDB, SQLite

Database goals:

- Reliable
- Small RAM footprint
- Fast
- Typically small data sets
- Typically limited data types



Closed Competition:

- Infinity Database
- Empress Database

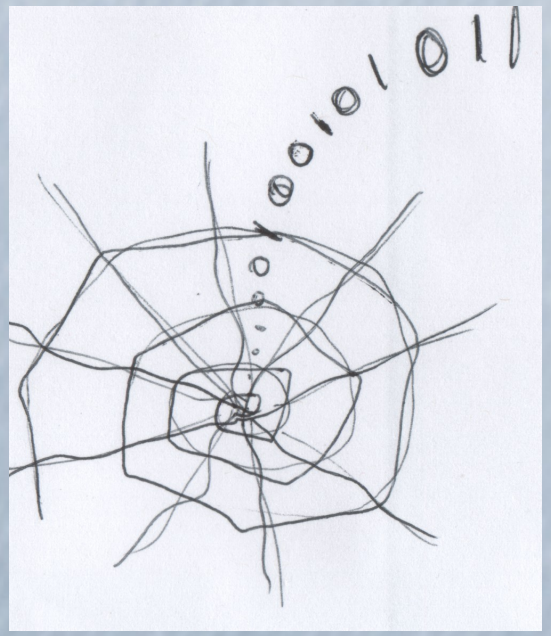
Embedded Databases
BerkeleyDB

- Native key-data B-Tree storage is fast and eliminates SQL
- Linked directly to application
- Dual Licensed
- Hot & Cold Backups and Upgrades
- Transactions (ACID)
- Replication
- Multi-Session
- Configurable Options
- Fast
- Optional XML Storage

Embedded Databases
SQLite

- Transactions (ACID)
- Zero configuration
- SQL92 or Native API
- Endian neutral
- Public Domain
- Exhaustive Test Suite
- Mutli-Read, Single-Write Access
- Options
  - Threadsafe
  - Large data types (BLOB fields)
  - SQL suppor

Everything's On the Net
GoAhead



Web Server goals:

- Reliable
- Small RAM footprint
- Fast
- Support web standards
- Support basic scripting, event links, etc.

Closed Competition:

- Netburner
- Seminole
- Fusion HTTP Server

Everything's On the Net
GoAhead WebServer

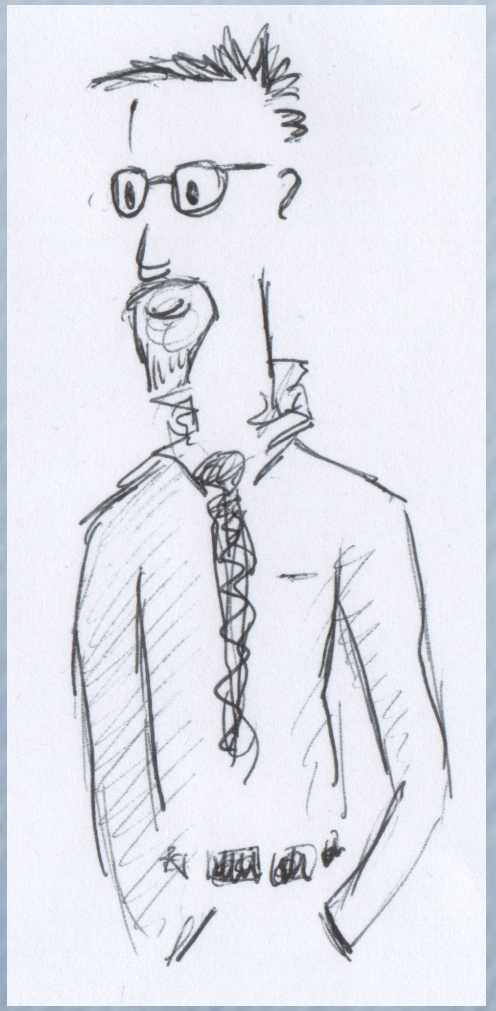
- Supports many OS's including Linux, RTEMS, and eCos
- HTTP 1.1
- Active Server pages
- Embedded JavaScript
- CGI
- SSL 3.0
- 60K memory footprint
- C
- ROMable

It's a Big FOSS World

- Operating Systems
- Editors
- Office Tools
- Communication / Collaboration Tools
- Scripting Languages
- Lint
- Emulators
- Modelling
- UML
- Version Control
- Change Management
- Auto-Documentation

Questions?

mvandervoord@gmail.com



Where To Find Out More

http://www.fsf.org

http://www.opensource.org

http://gcc.gnu.org

http://cxx.uclibc.org/

http://sourceware.org/newlib/

http://www.caravan.net/ec2plus

http://www.bell-labs.com/project/micromonitor/

http://www.cygwin.com/redboot/

http://www.embedded-linux.org/

http://www.rtems.com/

http://ecos.sourceware.org/

http://www.freertos.org/

http://www.sics.se/~adam/pt/

http://www.gnu.org/software/gdb/

http://www.eclipse.org/

http://www.eclipseplugincentral.com/

http://eclipse-plugins.2y.net/

http://www.trolltech.com/

http://www.boost.org/

http://www.sourceforge.net/

http://www.codeguru.com/

http://www.embedded.com/

http://bstring.sourceforge.net/

http://www.sleepycat.com/

Where To Find Out More

http://www.sics.se/~adam/contiki/

http://goahead/webserver/webserver.htm

http://www.sqlite.org/

http://subversion.tigris.org/

http://www.bugzilla.org/

http://www.openoffice.org/

http://www.gnome.org/projects/evolution/

http://www.firefox.com/

http://www.ruby-lang.org/

http://www.perl.org/

http://www.python.org/

http://www.stack.nl/~dimitri/doxygen/

www.google.com