Visualizing Resource Usage During Initialization of Embedded Systems

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Purpose

- Time from power-on to "usable system" is a critical user satisfaction component for consumer electronic devices
- Quantitative analysis of system initialization is useful for many tasks (i.e. analyzing kernel initialization w/ printk-times patch)
- Qualitative analysis is "fuzzier", but still useful

Why Visual Presentation of Resource Usage Data?

- User space initialization is somewhat complicated - straight numeric analysis could be difficult, without a full understanding of boot process
- All time spent from creation of init task to "usable system" will be considered the user space portion of system boot for this talk

bootchart is Born

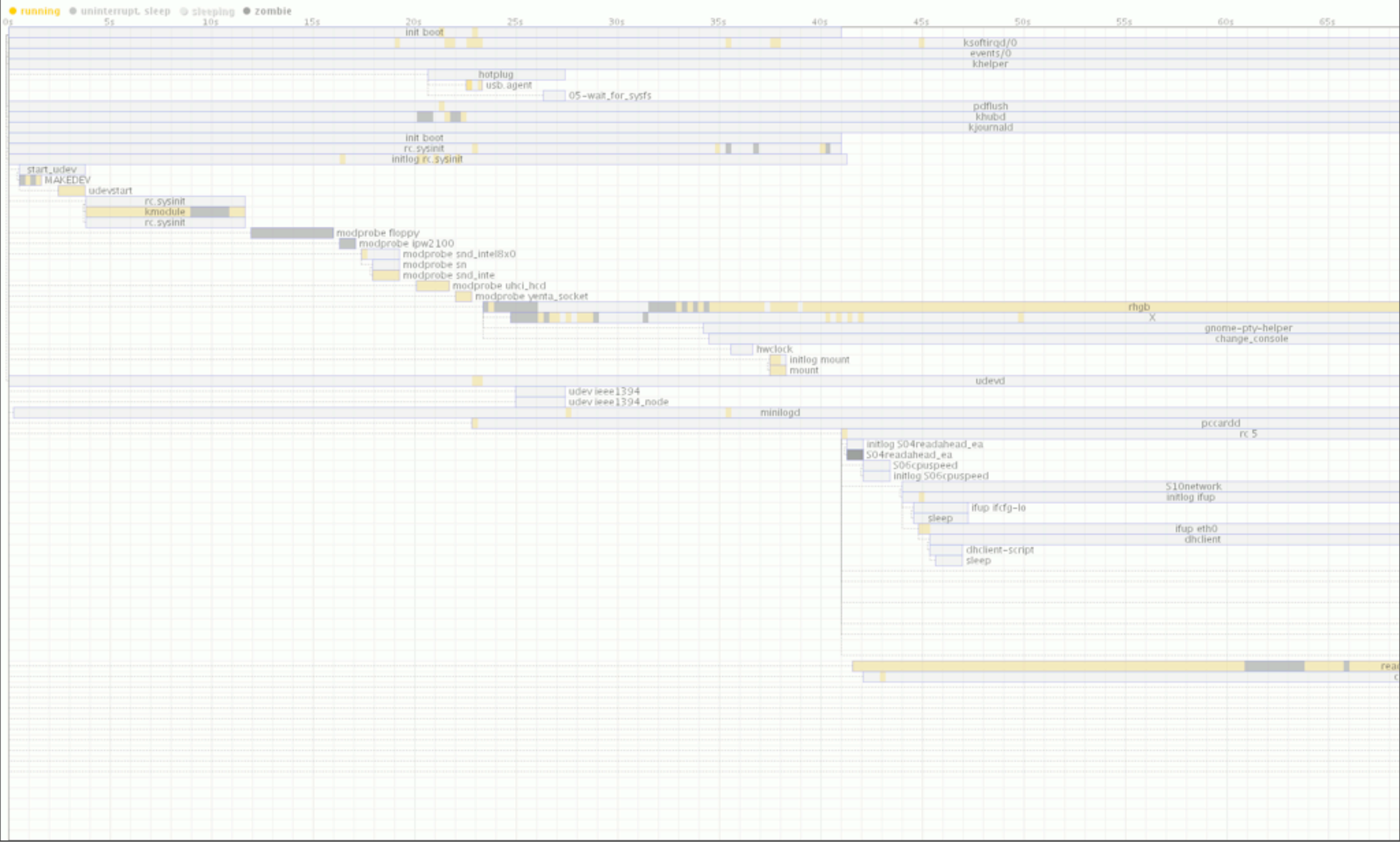
- bootchart tool written by Ziga Mahkovec in answer to the challenge on the Fedora mailing lists in November, 2004 by Owen Taylor:
  - *"The challenge is to create a single poster showing graphically what is going on during the boot, what is the utilization of resources, how the current boot differs from the ideal world of 100% disk and CPU utilization, and thus, where are the opportunities for optimization."*
- Allows system architects to see where system resources are being utilized, and where opportunities for optimization are available
- Linux distros such as Knoppix use bootchart to reduce boot time significantly through iterative improvements, starting with "low hanging fruit", and re-examination of their boot process (e.g. pre-loading pages from CD-ROM all at once)

bootchart Design

- Replaces init w/ data collection shell script
- Reads resource usage data from /proc filesystem
- Writes (well, copies) data to files in /tmp/ bootchart.XXXXXX tempdir
- Data collection stops when trigger application is found to be running -- that is system is usable (e.g. gdm, xdm, X server, getty, etc.)
- Image creation done in separate step, after all data collection is completed by parser-renderer application

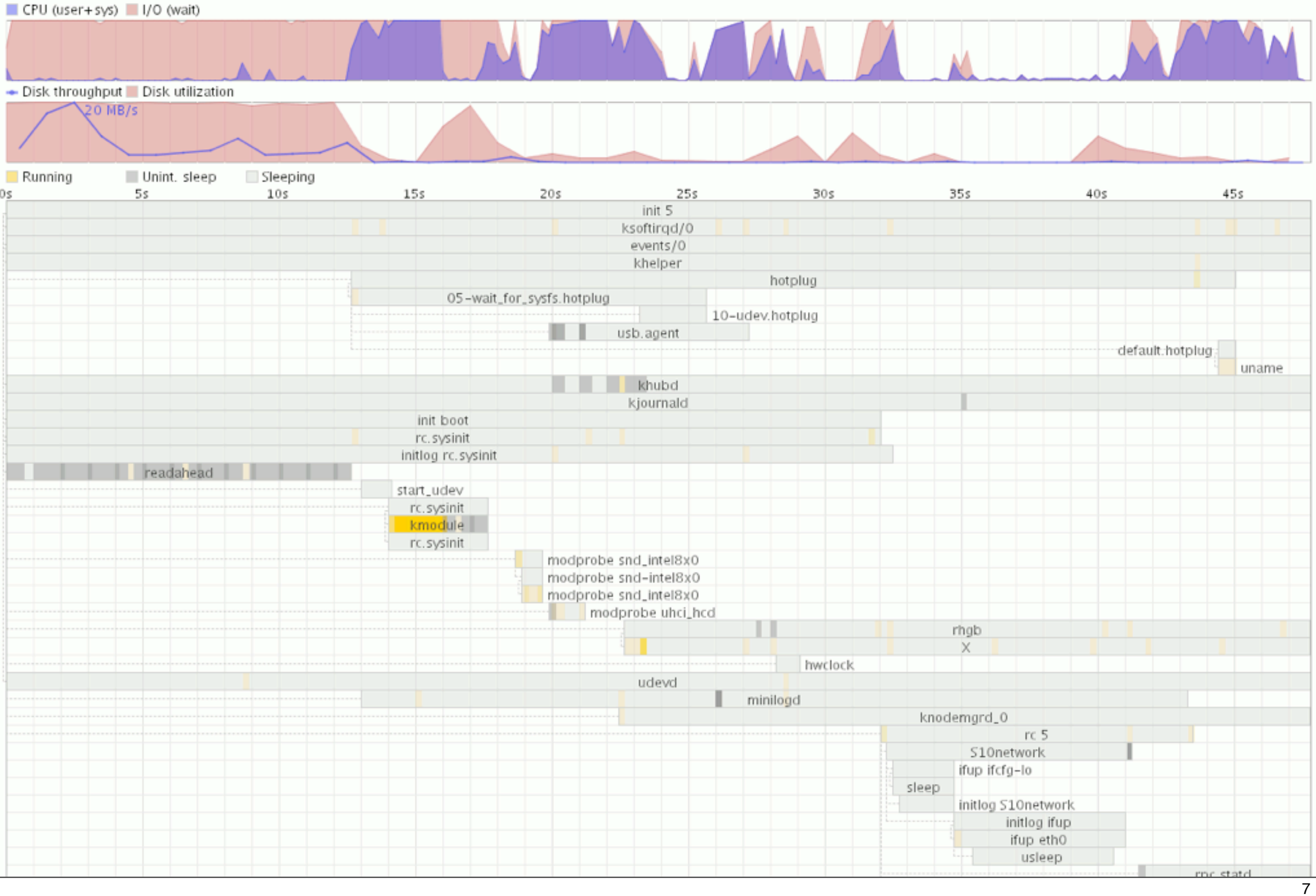
Boot chart for serenity.klika.si (Mon Nov 15 20:19:54 CET 2004)

Linux (none) 2.6.9-1.667 #1 Tue Nov 2 14:41:25 EST 2004 i686 i686 i386 GNU/Linux
Fedora Core release 3 (Heidelberg)
Intel(R) Pentium(R) M processor 1500MHz
cmdline: ro root=/dev/vg0/root vga=0x318 rhgb
boot time: 1:38



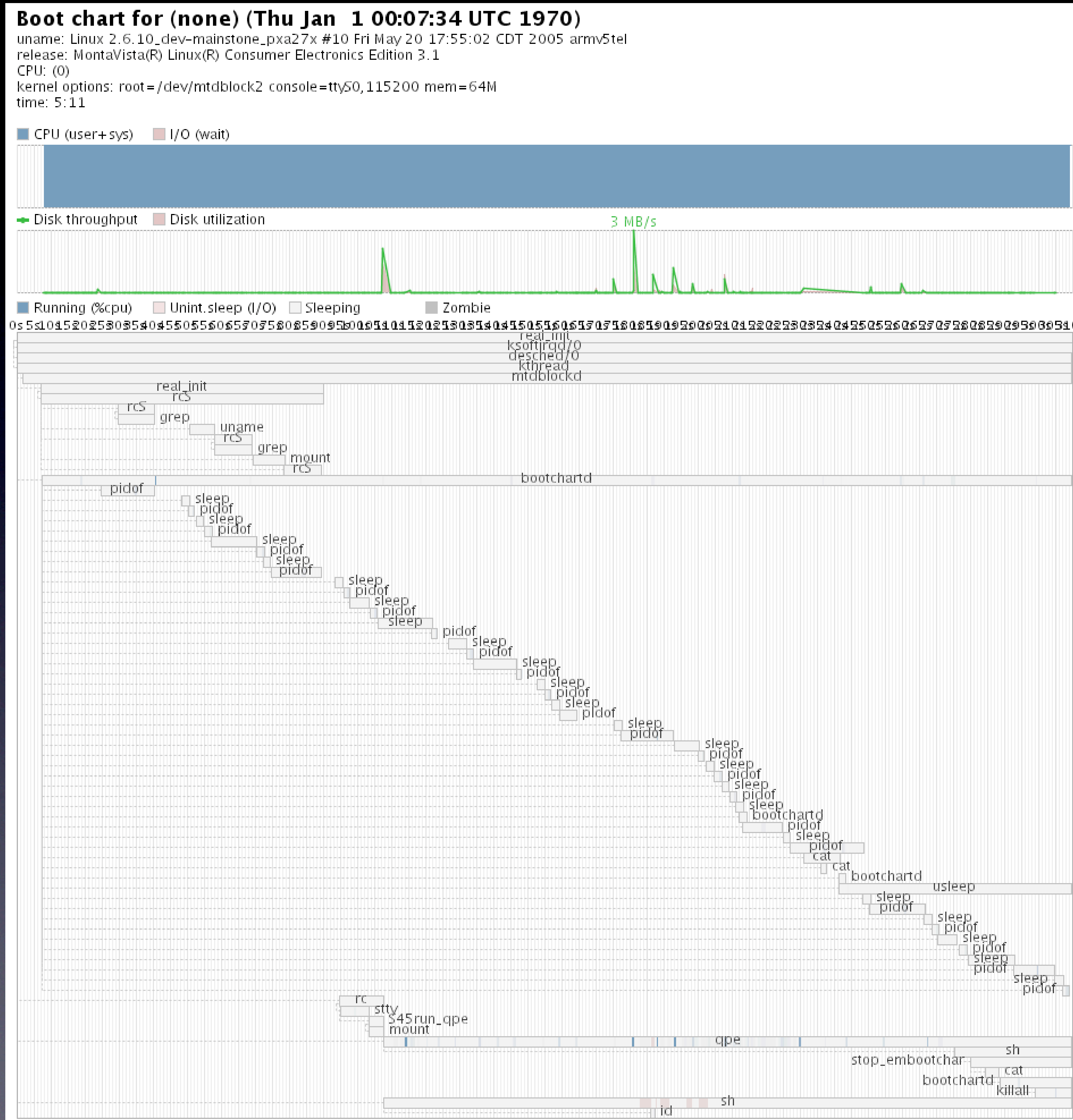
Boot chart for serenity.klika.si (Sun Nov 21 01:48:05 CET 2004)

uname: Linux (none) 2.6.9-1.667 #1 Tue Nov 2 14:41:25 EST 2004 i686 i686 i386 GNU/Linux
release: Fedora Core release 3 (Heidelberg)
CPU: Intel(R) Pentium(R) M processor 1500MHz
kernel options: cmdline: ro root=/dev/vg0/root vga=0x318 rhgb
boot time: 0:48



Awesome!

Let's try this on our embedded target system and see where it's spending all its time!


Boot chart for (none) (Thu Jan 1 00:07:34 UTC 1970)
uname: Linux 2.6.10_dev-mainstone_pxa27x #10 Fri May 20 17:55:02 CDT 2005 armv5tel
release: MontaVista(R) Linux(R) Consumer Electronics Edition 3.1
CPU: (0)
kernel options: root=/dev/mtdblock2 console=ttyS0,115200 mem=64M
time: 5:11
CPU (user+sys)
I/O (wait)
Disk throughput
Disk utilization
3 MB/s
Running (%cpu)
Unint.sleep (I/O)
Sleeping
Zombie
real_init
ksoftirqd/0
desched/0
kthread
mtdblockd
rcS
grep
uname
mount
bootchartd
pidof
sleep
cat
usleep
rc
stty
S45run_qpe
qpe
sh
stop_embootchar
killall
id

Not so good, eh?

- Using bootchart increased system boot time by at least order-of-magnitude
- What worked on a 1.5 GHz CPU w/ lots ‘o RAM & a fast HD doesn’t work so well on embedded system w/ limited resources

Causes of Performance Problems

Though the data collection tasks are "simple", a shell script is an inappropriate choice for implementation of data collector

- Using shell commands cause each action to require a fork()/ exec()
- When using commands like cat to copy files, each read() or write() requires a corresponding open() & following close()
- "polls" process list to find exit trigger event (uses pidof, which reads from /proc)
- These problems get much worse as:
  - # of processes increase (/proc/<pid> dirs are read)
  - sampling rate increases

How to Solve These Performance Problems?

Problems	Solutions
1) fork()/exec() for each sample?	Do all data collection in a single process
2) File I/O overhead too high?	open() files once, read/write many times.
3) Exit trigger event search too costly?	Use deterministic trigger.
4) Poor performance scalability?	Minimize impact of reading /proc files & directory.

embootchart Design Principles, I

- Meant to be an open source tool: tight and simple design & code
- Reuse the bootchart parser-renderer
  - Less code to write/maintain
  - Performance not an issue, so why bother?
  - This application is quite well done!
  - Adds a restriction: embootchart must now be data compatible w/ bootchart (no format changes of output data files)

embootchart Design Principles, 2

- Performance is absolutely critical to reduce skewing the results
- Because embedded systems should generally have shorter boot times, may need to increase sampling rate
  - bootchart default: 5 samples/sec.
  - embootchart default: 20 samples/sec.

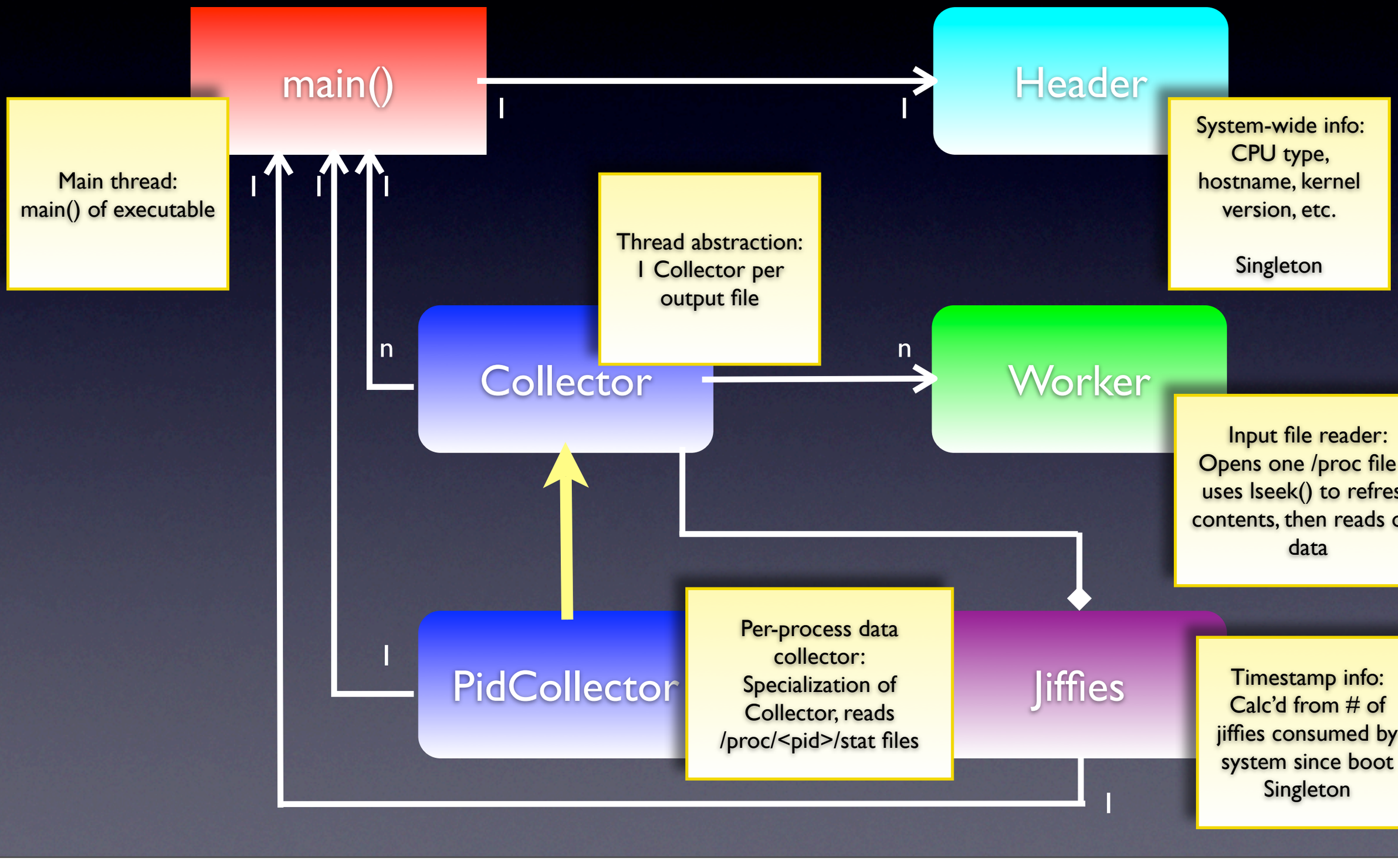
How to Achieve Higher Performance

- Single compiled, multi-threaded application
- Tasks divided one-per-thread
- Input & output files open()'d one time, read() & write multiple times
  - Output files use open(..., O_WRONLY | O_APPEND)
  - Input files use open(..., O_RDONLY) and lseek(fd, 0, SEEK_SET) to refresh data before sampling (/proc files!)
- Use asynchronous notification to stop data collection: signal from init script or modified application (e.g. gdm)

C++?!

- Because the data collector is easy to separate into discrete tasks, OO seemed a logical design choice
- Reasonably high performance & small code size (~350 LoC, 77kb binary, dynamically linked)
- libstdc++ functionality for file I/O, string manipulation, etc. reduces LoC I need to write/maintain, and is higher performance than hand-written code while shielding complexity
- Simplest way to get there from here

C++ Class Diagram



embootchart Data Acquisition Sequence

- embootchart launched
  - Run pre-initialization executable/script (optional)
  - fork(): run "real" init (i.e. /sbin/init) in parent process (pid 1), child process goes on to do data collection
    - Start & initialize data collector threads & let them collect data; main thread waits for exit signal
    - When exit signal (SIGSTOP) is rec'd, stop all data collector threads
    - Run post-processing executable/script (optional)
- embootchart exits

Pre-init script

Responsible for special set-up for data collection, not normally done for system boot

- Mount tmpfs for temp r/w of data output files
- Mount /proc fs for data acquisition
- Pre-init hardware setup (console setup, device symlinking, etc.)
- May replace a script already run on system (e.g. linuxrc)

Post-processing script

Responsible for packaging data & setting up resources for data export from target system

- tar & gzip datafiles, which is how parser-renderer expects them to be
- Set up networking or NFS filesystem for data export
- Any cleanup of data files, etc. after export, if your system is going to continue to run

embootchart Customization

- Modify Makefile to customize gross functionality
  - Whether to collect disk usage statistics (2.6.x kernels or higher)
  - Whether to run pre-init script
  - Whether to run post-init script
- Modify Config.hh file to fine-tune parameters at compile time
  - Sampling rate (default: 20 samples/sec.)
  - Filepath to "real" init process
  - Filepaths to pre-init and post-processing scripts
  - Location of rw filesystem to output data files

Contrived Example: Mainstone Reference Platform

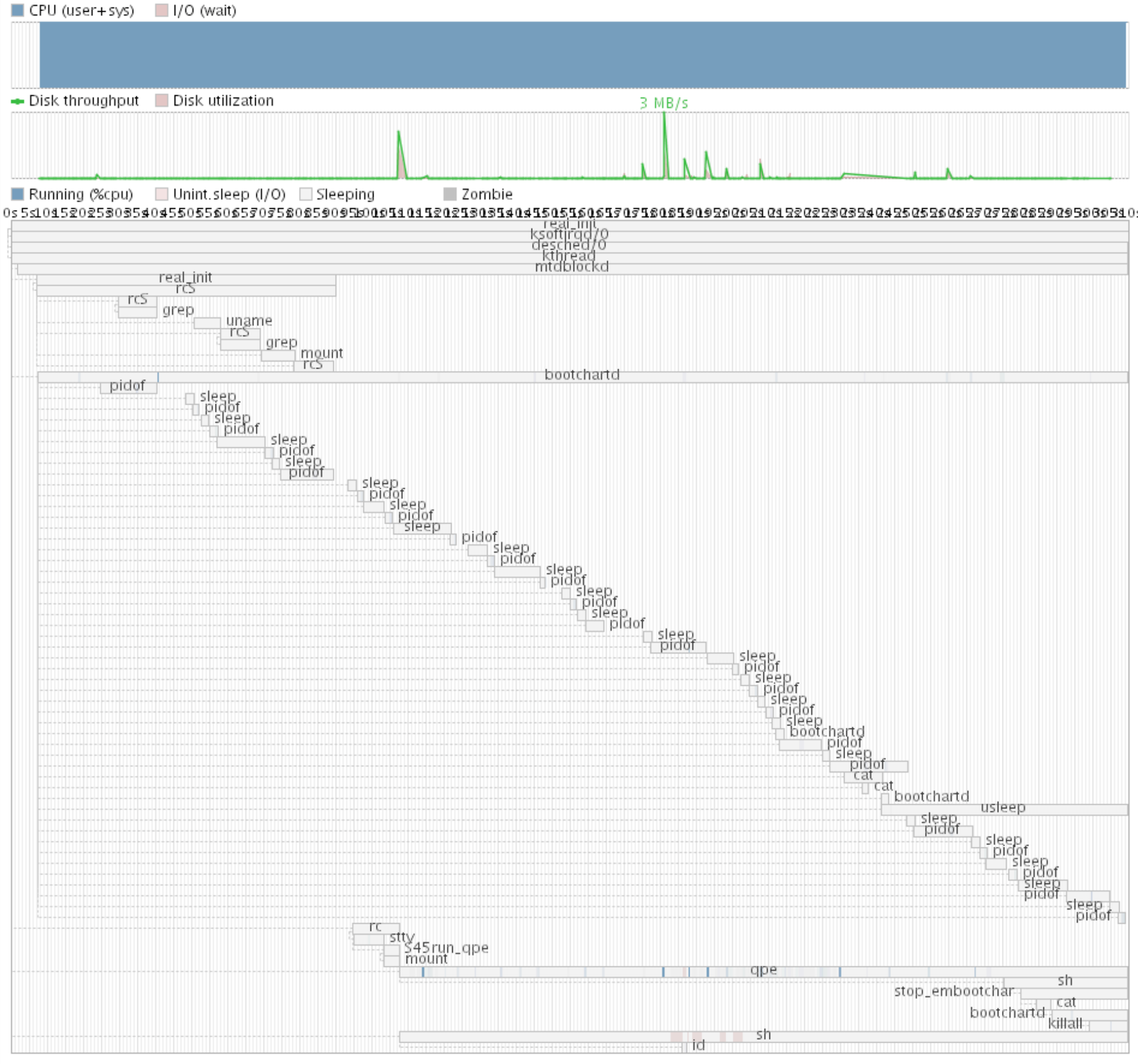
- 200 MHz Intel XScale (PXA270, iwmmxt_le) CPU
  - 16-bit memory bus
  - 32 entry text & data TLB caches
- 64 MB RAM
- 32 MB Tyax Flash (NOR)
- Based on MontaVista 3.1 CEE Linux distribution (glibc 2.3.2, gcc-3.2)
  - Linux 2.6.10 kernel (upgrade over MVLCEE 3.1)
  - busybox 1.00-rc3
  - QTopia 2.2.0 free edition, PDA edition (http://www.trolltech.com/products/qtopia/index.html)

Warning!

I said "contrived" on the previous slide because this is not a real-world target system. Due to the simplicity of its purpose (i.e. show some bootcharts!), there are not as many low-hanging fruit as I would like for demonstration purposes.

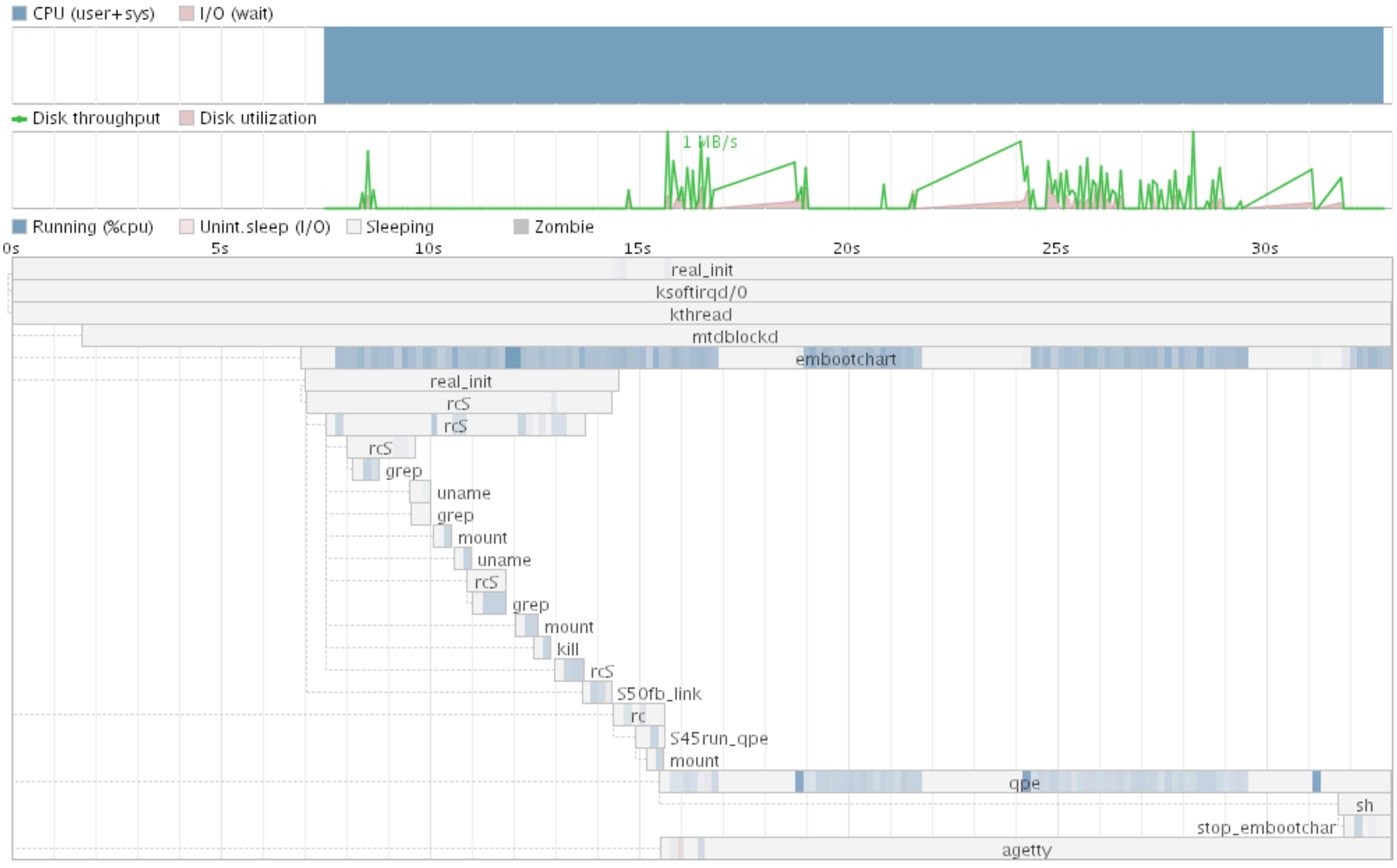
Boot chart for (none) (Thu Jan 1 00:07:34 UTC 1970)

uname: Linux 2.6.10_dev-mainstone_pxa27x #10 Fri May 20 17:55:02 CDT 2005 armv5tel
release: MontaVista(R) Linux(R) Consumer Electronics Edition 3.1
CPU: (0)
kernel options: root=/dev/mtdblock2 console=ttyS0,115200 mem=64M
time: 5:11



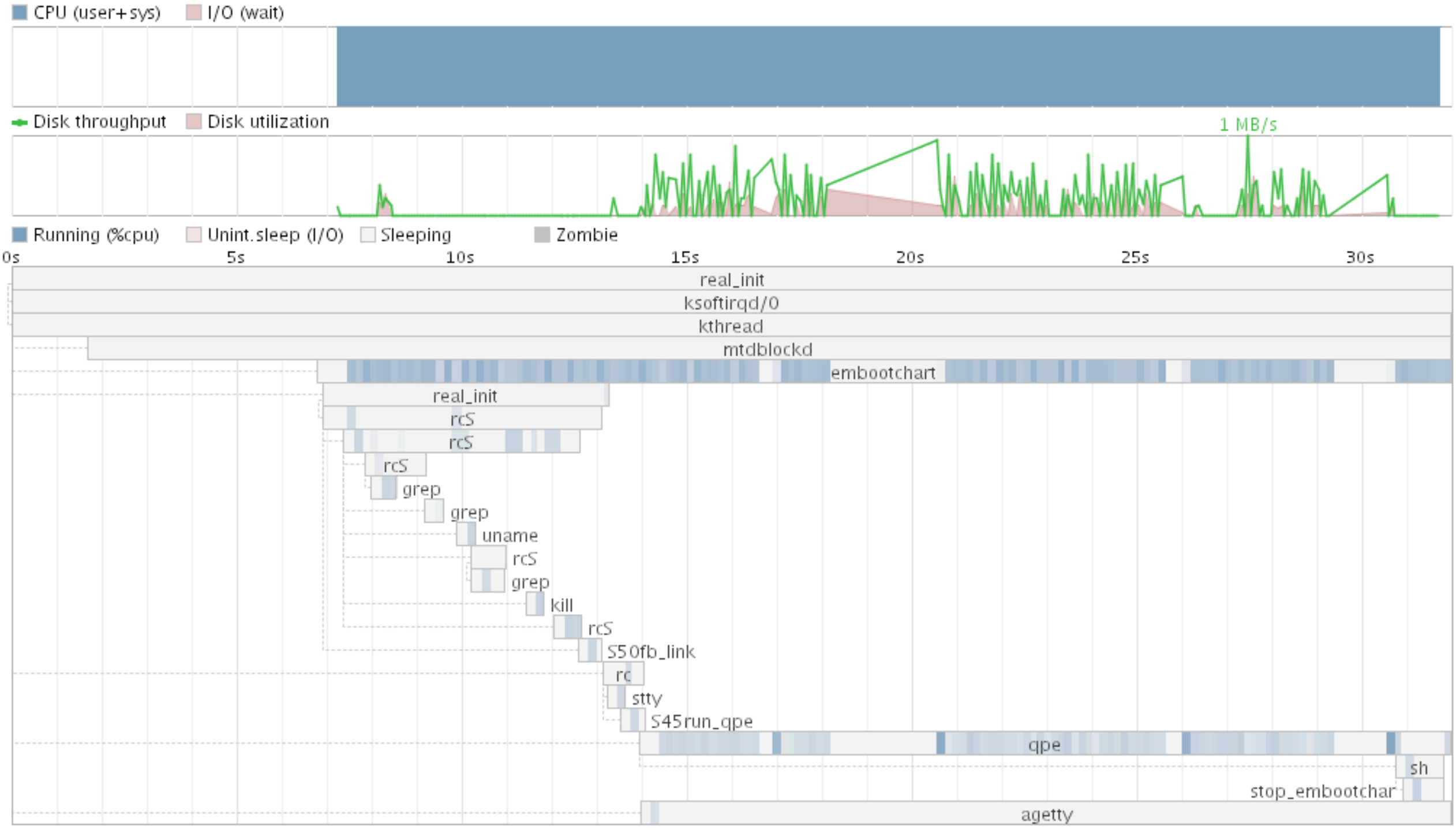
Boot chart for (none) (Thu Jan 01 00:00:28 UTC 1970)

uname: Linux version 2.6.10_dev-mainstone_pxa27x (fishburn@virgil) (gcc version 3.4.3 (MontaVista 3.4.3-21.0.0.custom 2005-04-13)) #10 Fri May 20 17:55:02 CDT 2
release: MontaVista(R) Linux(R) Consumer Electronics Edition 3.1
CPU: (0)
kernel options: root=/dev/mtdblock2 console=ttyS0,115200 mem=64M
time: 0:34



Boot chart for (none) (Thu Jan 01 00:00:28 UTC 1970)

uname: Linux version 2.6.10_dev-mainstone_pxa27x (fishburn@virgil) (gcc version 3.4.3 (MontaVista 3.4.3-21.0.0.custom 2005-04-13)) #10 Fri May 20 17:55:02 CDT 20
release: MontaVista(R) Linux(R) Consumer Electronics Edition 3.1
CPU: (0)
kernel options: root=/dev/mtdblock2 console=ttyS0,115200 mem=64M
time: 0:33



What Next?

- Reduce need for external script/executable for pre-init & post-processing stages by writing common tasks (e.g. mounting filesystems) as C+ + modules
- Extend data collection to cover memory usage
- Attempt to identify further performance improvements in existing code (e.g. remove the user of /proc all together?!)

Great!
Where do I get it?

- Process started to open-source this project & distribute to CELF & RotW
- When approved, embootchart will be released under GPL (most likely)
- Will publicize on CELF mailing list
- This should happen fairly quickly (weeks, not months)