Embedded Linux Optimization Techniques:
How Not To Be Slow ?

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Alcatel·Lucent

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About Me …

ALCATEL LUCENT	**SOFTWARE ARCHITECT** • Expert and Evangelist on Open Source Software. • 8y experience on various multimedia/network embedded devices design. • From low-level BSP integration to global applicative software architecture.
OPEN SOURCE	**PROJECT FOUNDER, LEADER AND/OR CONTRIBUTOR FOR:** • OpenBricks — Embedded Linux cross-build framework. • GeeXboX — Embedded multimedia HTPC distribution. • Enna — EFL Media Center. • uShare — UPnP A/V and DLNA Media Server. • MPlayer — Linux media player application.
EMBEDDED LINUX CONFERENCE	**FORMER EDITIONS SPEAKER** • ELC 2010 — GeeXboX Enna: Embedded Media Center. • ELC-E 2010 — State of Multimedia in 2010 Embedded Linux Devices.

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About My Job …

From our “**IP Touch**” IP phone …

- MIPS32 @ 275 MHz.
- 8/16 MB RAM, 4/8/16 MB NOR.
- Physical keys input.
- Basic 2D framebuffer display.
- Powered by VxWorks OS.

… to next-generation enterprise IP phones.

- Brainstorming exercise from our R&D Labs.
- Introduced as a proof-of-concept feasibility study, allowing us to explore modern Linux technologies.
- **Early Requirements:**
  - Powered by GNU/Linux OS, not Android.
  - Open to HTML/JS-based WebApps.
  - Remaining parts are open to imagination.

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What You May Expect …

- **Return of experience from feasibility study:**
  - You may want to see this presentation as one big exercise.
  - It won’t help you boost your system (sorry folks ☹).
  - But hopefully it’ll prevent you from facing some common troubles.
- **Share a few tips and tricks for:**
  - Correctly choosing your hardware.
  - Wisely selecting your software architecture and components.
  - Measuring and profiling your system.
  - Isolating the performances bottlenecks.
  - Optimizing your Linux embedded system.
- **Ultimately, avoid your software to be slow by design.**

Preamble

In 20 years (from my i286 Desktop to my Core i5 laptop):

- My CPU got 10000x faster.
- My RAM got 12800x bigger (and faster).
- My HDD got 8192x times bigger (and faster).

And yet my PC takes ages to boot
and I need more time to open up my text editor ...

Seriously, What Went Wrong ???

Rule #1:
Know Your Hardware !

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Common Considerations …

- **CPU SIMD Optimizations and Execution Modes:**
  - **Thumb-1/2:** Tradeoff between code size and efficiency …
  - **Jazelle:** Don’t do JAVA on ARM without it !
  - **VFP / NEON:** Impressive performance boost on all FPU operations;
    Use integer-based routines otherwise.

  => Tradeoff between performances and portability (generic builds are meant for portability).

- **Audio Management:**
  - Choice #1: Legacy hardware DSP audio decoding (with complex shmem architecture) ?
  - Choice #2: Software Cortex-A9 audio decoding (within 50 MHz or so) ?

- **Display / Input Optimizations:**
  - **GPU Capabilities:** 2D blitting, 3D, post-processing ?
    Ensure you’ll never fail into software fallback !
    Don’t bother rendering more frames than your LCD can display.
  - **TouchScreen:** Calibrate your driver not to read more often than your max display FPS rate.
    Reading on I2C consumes resources that you may never be able to interpret.

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Embedded SoC Comparison …

	Our Test Case SoC	Apple iPhone 3GS	Apple iPhone 4	Samsung Galaxy S2	Today PC
Introduction Date	2009	2009	2010	2011	2011
CPU	ARM1176	ARM Cortex-A8	ARM Cortex-A8	ARM Cortex-A9 MP	Intel Core-i5 2500T
Frequency (MHZ)	500	600	1000	2 x 1200	4 x 2300
Memory Size (MB)	256	256	512	1024	Unlimited
L2 Cache Size (kB)	None	256	640	1024	6144
FPU	No	Yes	Yes	Yes	Yes
Specialized Instructions	Thumb-1, Jazelle	Thumb-2, Jazelle, VFPv3, NEON	Thumb-2, Jazelle, VFPv3, NEON	Thumb-2, Jazelle, VFPv3, NEON	MMX, SSEx
Hardware GFX	Limited 2D Blitter	Full 3D	Full 3D	Full 3D	Full 3D
Hardware Video Engine	Limited SD	Limited SD	Limited HD	Full HD	Full HD
Memory Bandwidth (GB/s)	1.33	1.6	3.2	6.4	21.3
Performances (DMIPS)	625 (1.25 DMIPS/MHz)	1200 (2.00 DMIPS/MHz)	2000 (2.00 DMIPS/MHz)	6000 (2.5 DMIPS/MHz/Core)	59800 (6.5 DMIPS/MHz/Core)
CPU PC Equivalency	Pentium Pro @ 233 MHz (1996)	Pentium II @ 400 MHZ (1998)	Pentium III @ 600 MHz (2000)	2x ATOM @ 1.3 GHz (2008)	*N.A.*

Rule #2:
Embedded is NOT Desktop !

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Embedded is NOT Desktop …

- **Brutal Facts:**
  - Embedded devices get more and more powerful each year.
  - But not everybody uses high-end ARM SoCs.
  - Still resources limited: CPU, memory bandwidth, run on batteries, slow I/Os ...

So why would you use the same kind of software than on a PC ?

Android somehow came out and diverged from GNU/Linux for some reason ...

- **Good Hints on some desktop-oriented performances eating software/technologies:**
  - Abstraction Framework,
  - Messaging Bus,
  - Garbage Collector,
  - Virtual Machine,
  - Interpreted Language,
  - XML,
  - Data Parsing and Serialization.

Use these with care !
Badly used, they are sources of terrible difficulties.

Rule #3:
Isolate Your System’s Bottlenecks !

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Measurement and Benchmarking …

- Optimization requires accurate measurement.
- Measure must:
  - Be deterministic and repeatable.
  - Not impact system's behavior.
  - Be the less intrusive as possible.
- Try to cover as much usability scenarios as possible; don't limit yourself to average Joe use cases.

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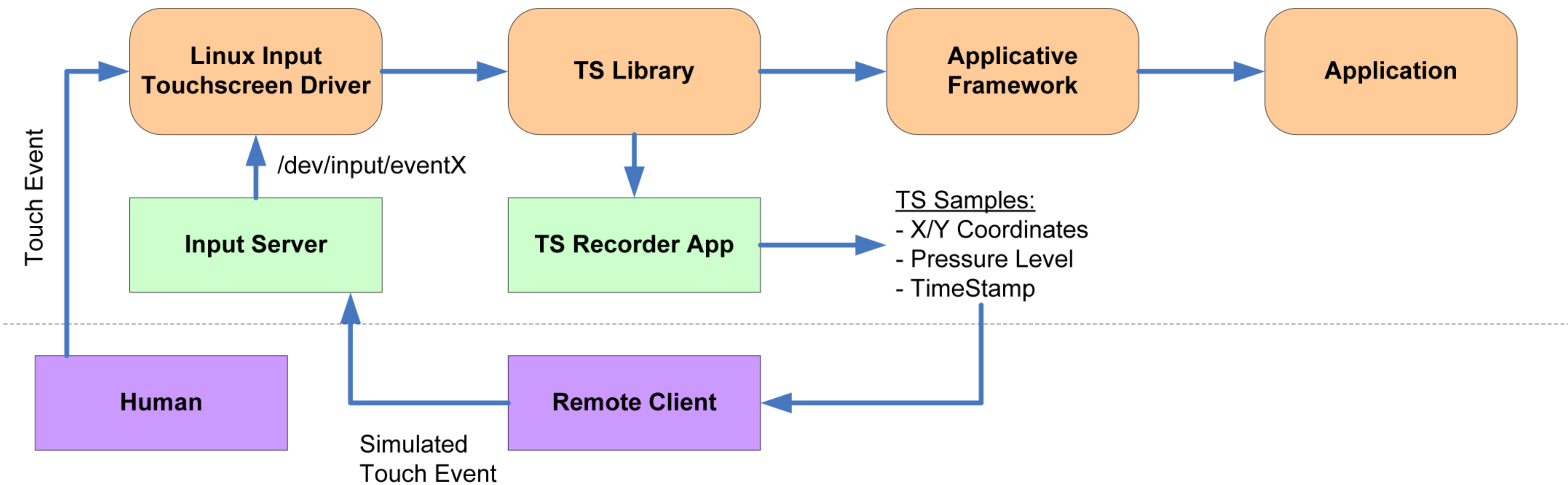
Benchmarking: An External Approach (1/2) …

- **Need for global feature/solution benchmark (<u>requires end-to-end implementation</u>)**
  - **At Input Level:**



- Record scenario: At **tslib** level, we retrieve X/Y coordinates, pressure level and timestamp.
- Replay scenario: We inject raw data to /dev/input/eventX and let the software handle events.
  - => Least intrusive input (mimics final human behavior).
- Can also be fully automated through simple client/server approach.

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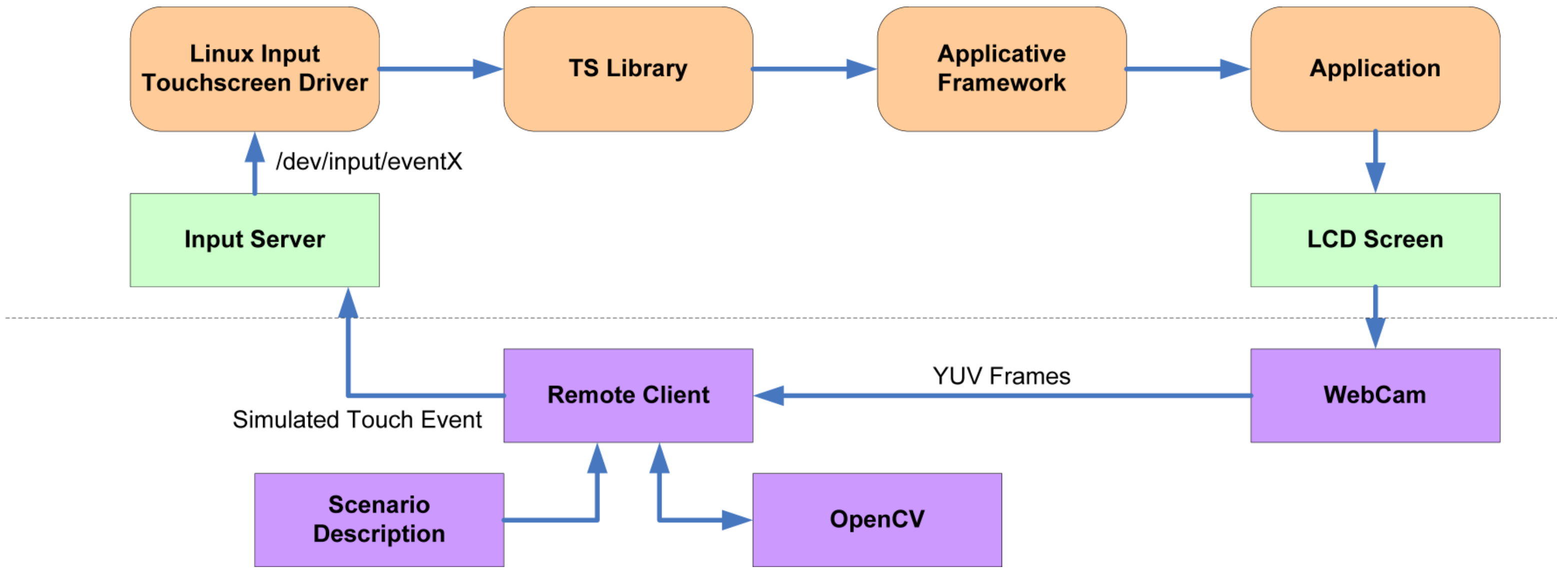
Benchmarking: An External Approach (2/2) ...

- **At Output Level:**



- External video camera recording.
- Need to define scenario start and end conditions (e.g. some widgets appearance / disappearance).
- On a remote PC, play back the recorded video to measure delta between start/stop conditions using **OpenCV** libraries.
  - Measure is the least intrusive (no impact on target).
  - Can be used for non-regression tests on a given global feature.
  - But you still have no clue which exact part of your code is slow.
  - Accuracy depends on camera's capability (usually 30fps, so 33ms minimum threshold).

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Benchmarking: An Internal Approach …

- **Modern Linux kernel introduced support for hardware counters**
  - Introduced as **Performance Counters** (see http://goo.gl/LldPv) in 2.6.31.
  - Renamed as **Performance Events** (see http://goo.gl/KWIfo) in 2.6.32+
  - Successor of **Oprofile**.
  - See tools/perf/ directory in kernel.

- **Example of usage (on OMAP 4430 Pandaboard):**
  - Requirements: You need debugging symbols to accurately trace your system.
  - User-space Profiling: perf top –U
  - Kernel–space Profiling: perf top -K

```
------------------------------------------------------------
   PerfTop:    9111 irqs/sec  kernel:99.2%  exact:
------------------------------------------------------------

             samples  pcnt function      DSO
             _______  _____ ____________ _________

              147.00 32.9% __muldf3      /root/mac
               69.00 15.4% main          /root/mac
               54.00 12.1% __aeabi_fadd  /root/mac
               50.00 11.2% __subdf3      /root/mac
               47.00 10.5% __aeabi_fmul  /root/mac
               32.00  7.2% __floatsidf   /root/mac
               25.00  5.6% __aeabi_d2f   /root/mac
               23.00  5.1% vmac_c        /root/mac
```

```
-------------------------------------------------------------------------------------------------
 PerfTop:   29341 irqs/sec  kernel:85.8%  exact:  0.0% [1000Hz cpu-clock-msecs],  (all, 2 CPUs)
-------------------------------------------------------------------------------------------------

          samples  pcnt function                     DSO
          _______  _____ ___________________________ ____________________________________________

          8842.00 22.3% _raw_spin_unlock_irq         [kernel.kallsyms]
          6326.00 15.9% _raw_spin_unlock_irqrestore  [kernel.kallsyms]
          3197.00  8.0% PVRSRVSetDCDstRectKM         /lib/modules/2.6.38.2/kernel/drivers/gpu/pvr/pvrsrvkm.ko
          2975.00  7.5% tick_nohz_stop_sched_tick    [kernel.kallsyms]
          1647.00  4.1% debug_smp_processor_id       [kernel.kallsyms]
           760.00  1.9% sub_preempt_count            [kernel.kallsyms]
           693.00  1.7% add_preempt_count            [kernel.kallsyms]
           617.00  1.6% drm_ioctl                    [kernel.kallsyms]
           588.00  1.5% get_parent_ip                [kernel.kallsyms]
           546.00  1.4% vector_swi                   [kernel.kallsyms]
           456.00  1.1% schedule                     [kernel.kallsyms]
           436.00  1.1% do_select                    [kernel.kallsyms]
           434.00  1.1% __copy_from_user             [kernel.kallsyms]
           404.00  1.0% unix_stream_recvmsg          [kernel.kallsyms]
```

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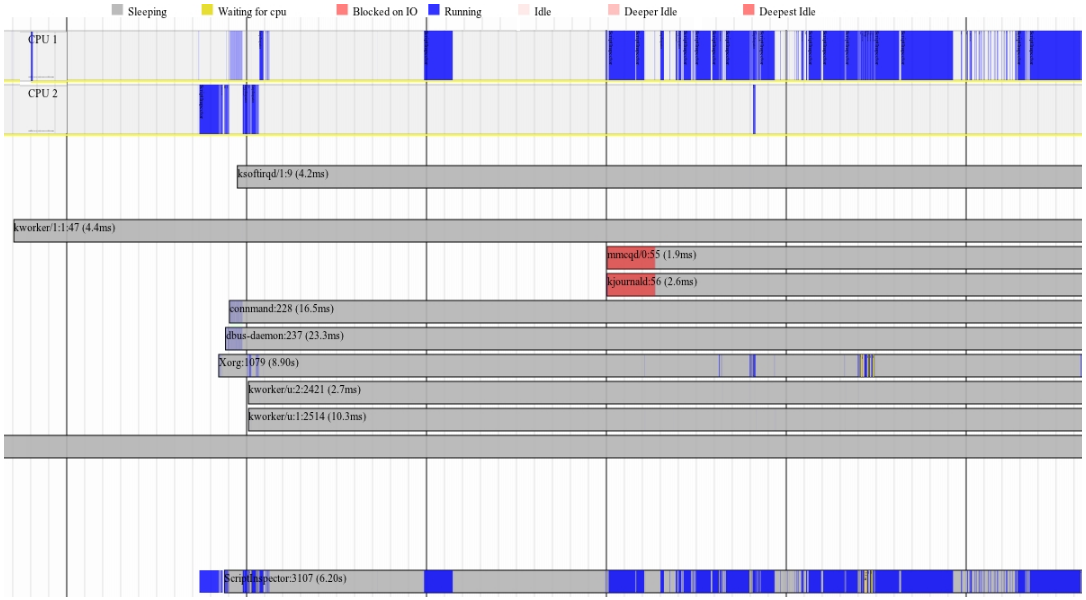
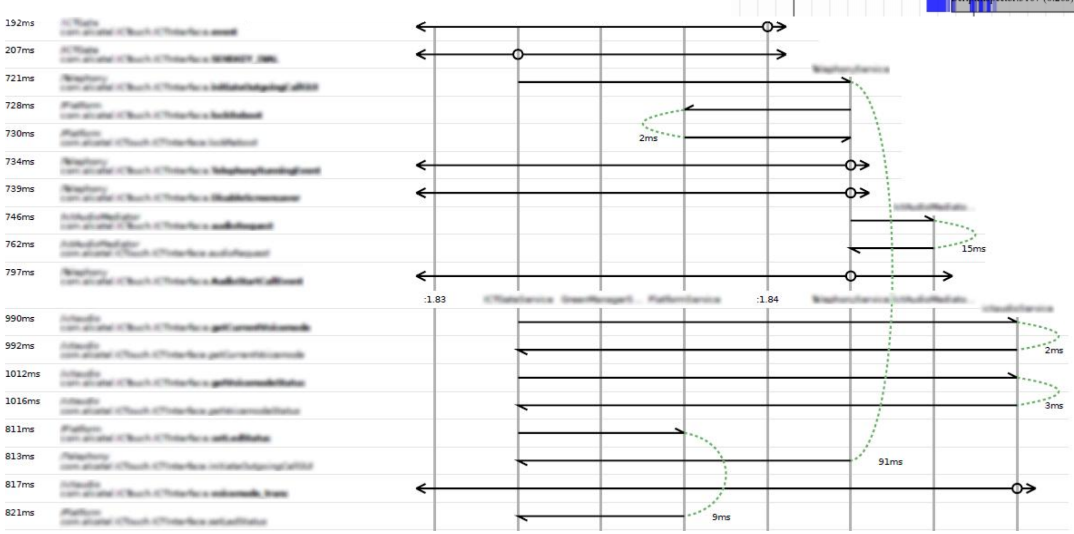
Determining Workflows …

Perftools also can be used for global system profiling by generating a time chart:

- On target:
  perf timechart record
  (will generate your perf.data samples).
- On host:
  perf timechart –i perf.data –o output.svg





D-Bus events messaging can be generated using **dbus-monitor**, or better, **bustle**.

- Though very intrusive (impacts on performances).
- Can be extended to include **tcpdump** network messages into workflow.
- See http://willthompson.co.uk/bustle/ for more details.

Rule #4:
Kill the Message Bus !

"~~Don't~~ Shoot The Messenger", *Shakespeare, 1598*

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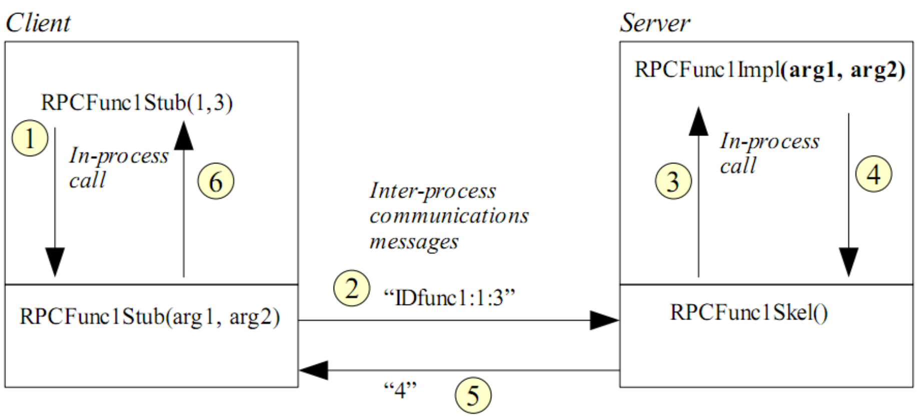
RPC Frameworks Comparison …

- **Study about different RPC architectures:**
  - Basic RPC function call between client and server.
  - Measure consists of 10000 calls
    on an AMD Athlon XP 2800+, 1 GB RAM.



- **Interesting results,**
  CORBA is known to be slow but:
  - **DCOP is 3x slower.**
  - **DBUS is 18x slower.**

	CORBA (ms)	DCOP (ms)	D-Bus (ms)
VOID Call	626	1769	9783
IN Integer Call	629	1859	10469
OUT Integer Call	660	1824	10399
IN/OUT Integer Call	686	1903	11162
IN String Call	650	1902	10510
OUT String Call	730	1870	10455
IN/OUT String Call	682	1952	11239

- **Full analysis details are available at:**
  - http://eleceng.dit.ie/frank/rpc/CORBAGnomeDBUSPerformanceAnalysis.pdf

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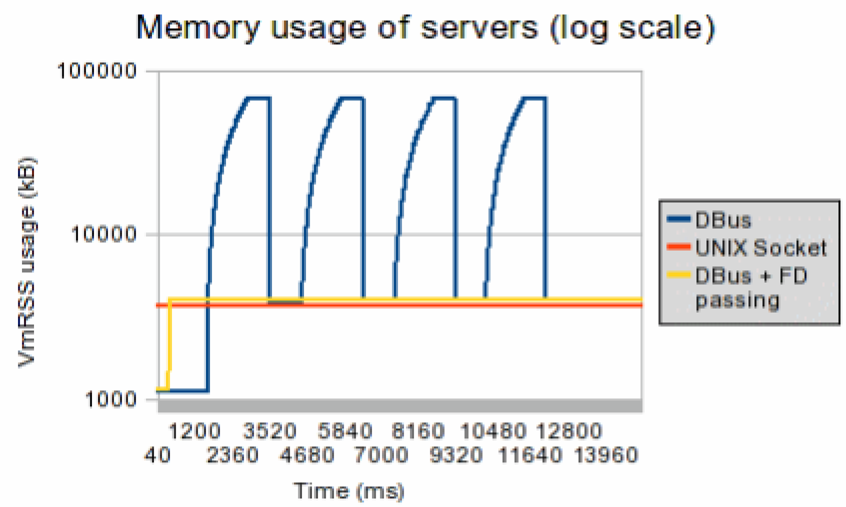
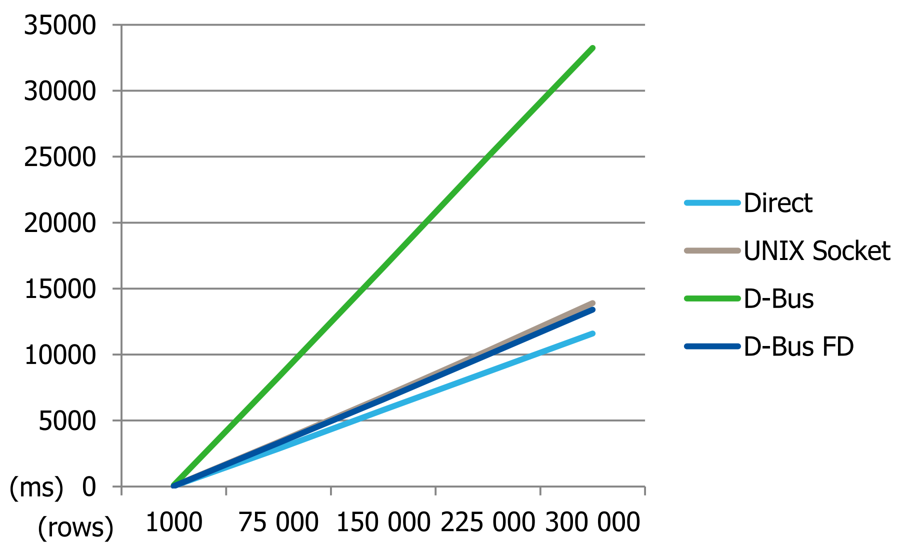
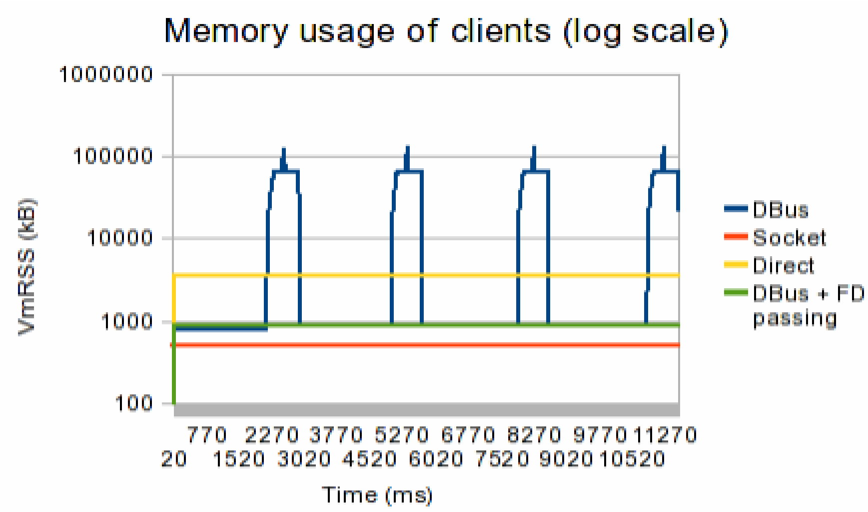
Messaging Benchmarks …

- **Some IPC benchmark figures:**
  - Performed on TI Pandaboard (TI OMAP 4430 @ 2x 1GHz).
  - Reading rows from a SQLite database (75k rows chunks).
  - **Different use cases:**
    - Native SQLite direct library function call.
    - Client/Server approach with UNIX sockets messaging channel.
    - Client/Server approach with D-Bus messaging channel.
    - Client/Server approach with D-Bus messaging channel with file descriptor support.
- See "**IPC Performance**" utility (http://goo.gl/5ygSU).







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D-Bus Messaging: Be Careful …

- D-Bus really is meant only for eventing/broadcasting; avoid passing data on it.
- There are more efficient and straightforward alternatives between 2 applications.
- Avoid passing large data: use D-Bus with UNIX file descriptor support instead.

- Remove paranoid message header/body checks/assertions:

```
diff -Naur dbus-1.5.0.orig/dbus/dbus-message.c dbus-1.5.0/dbus/dbus-message.c
--- dbus-1.5.0.orig/dbus/dbus-message.c        2011-08-06 12:31:50.624248071 +0200
+++ dbus-1.5.0/dbus/dbus-message.c      2011-08-06 12:32:49.264248103 +0200
@@ -3955,7 +3955,7 @@
   DBusValidationMode mode;
   dbus_uint32_t n_unix_fds = 0;

-  mode = DBUS_VALIDATION_MODE_DATA_IS_UNTRUSTED;
+  mode = DBUS_VALIDATION_MODE_WE_TRUST_THIS_DATA_ABSOLUTELY;

   oom = FALSE;
```

25% D-Bus Messaging Speedup

Rule #5:
Go Native !!!

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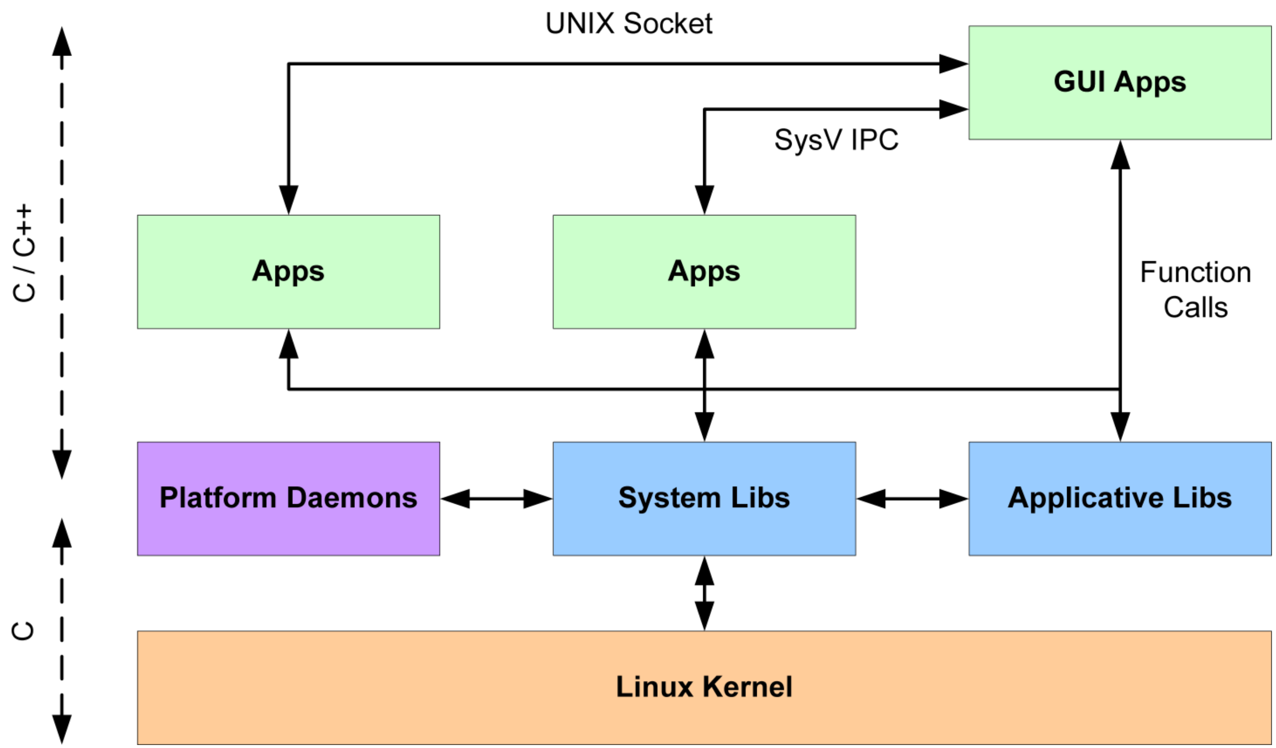
Desktop Software Architecture Comparison …

- **Desktop Legacy Applicative Architecture Sample:**
  - C/C++ code.
  - Graphical applications using native function calls to libraries.
  - Eventing through signals.
  - IPC through SysV IPC or UNIX /TCPIP Sockets.
  - Mastered memory usage.
  - Easily debuggable (using gdb or valgrind).
  - Easily profilable (using gcov, Oprofile, or Linux PerfTools).



Application's portability, skin-ability and easiness of deployment really depends on how you write your code ☹

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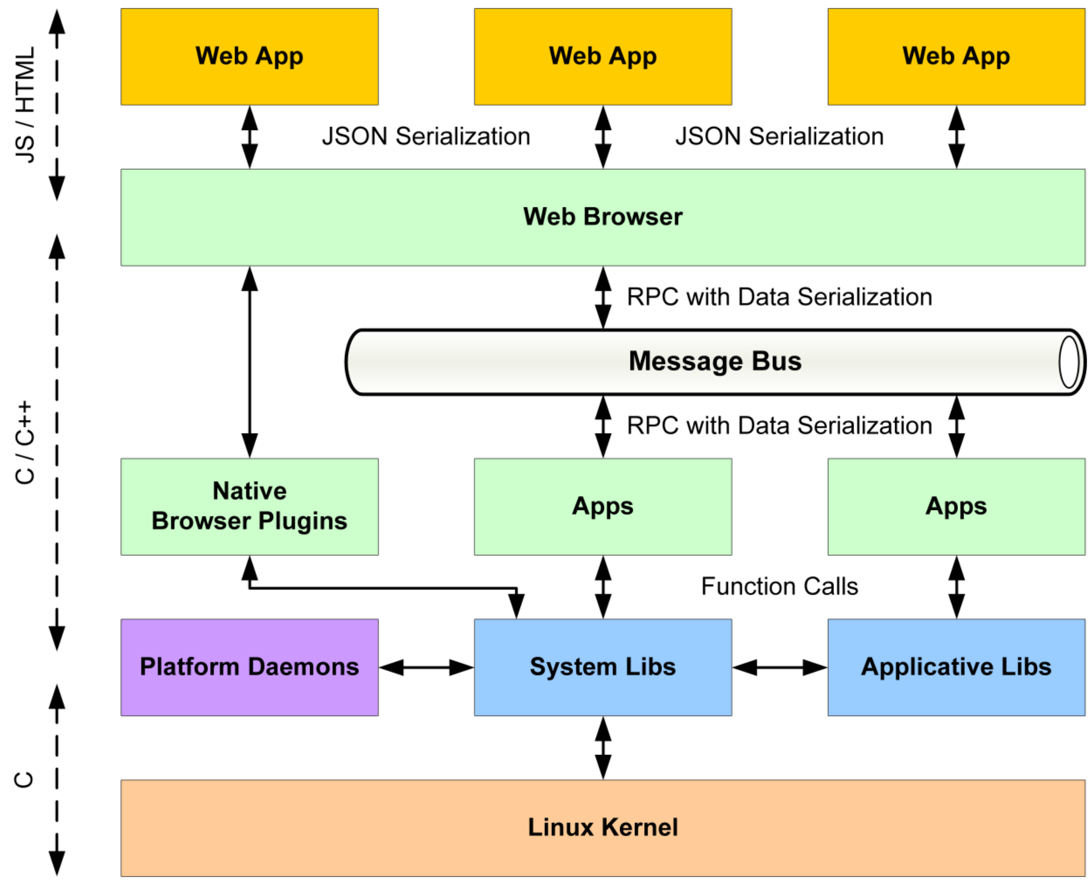
Desktop Software Architecture Comparison …

- **Desktop Web Applicative Architecture Sample:**
  - JS/HTML/CSS code.
  - Graphical user application using interpreted JavaScript functions with bindings to native middleware apps/libs.
  - WebServices usage and JSON data (de)serialization to exchange with middleware apps.
  - JavaScript-based Apps:
    - Easy and fast to write.
    - Even easier to skin, customize and deploy.
    - But interpreted and compiled in time, making them really hard to impossible to properly debug and/or profile.
    - Slower than any native equivalent.

Tradeoff needs to be made.



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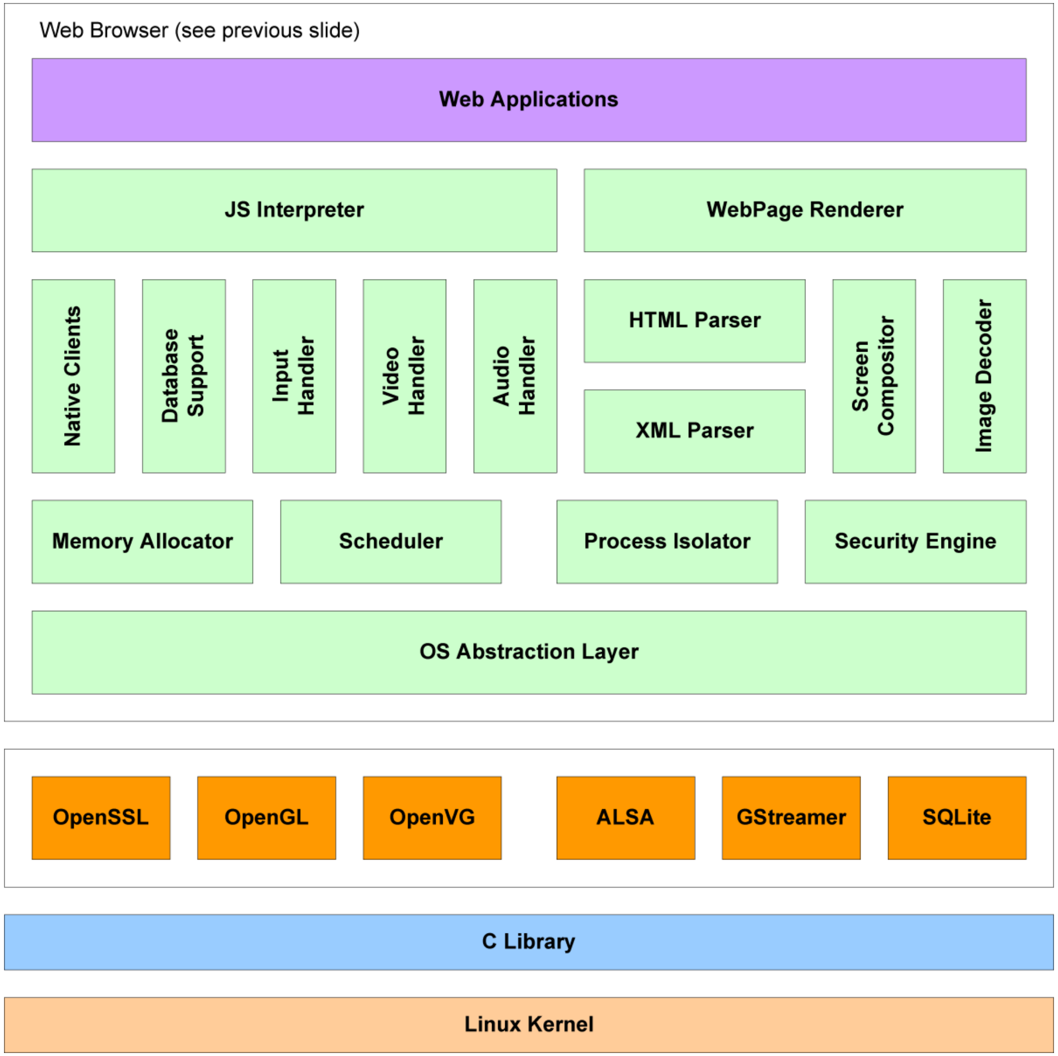
Browser Architecture Perspective: A Virtualized OS…

- **Browser Architecture:**
  - Makes JS portable to your legacy OS.
  - Specific bindings for OS and architectures.
  - Specifically designed modules to access the hardware beneath (audio, video, graphics, WebGL ...).
- **OS Concepts:**
  - Scheduler and Memory Allocator.
  - Applications Security / Sandboxing ...
- **Bindings for OS native services:**
  - HTML5 Local Storage
  - HTML5 Audio/Video tags …

Modern browsers are to JavaScript what POSIX used to be for C.



Conclusion

The Embedded Linux Rules Set …

Know Your hardware.

Embedded is NOT Desktop.

Isolate Your System's Bottlenecks.

Kill the Message Bus.

Go Native !

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Conclusion …

- **Your SoC never has been that powerful …**
  - … ain't a reason for wasting it though.

- **Don't mimic software development trend !**
  - Embedded Systems aren't desktop PCs.
  - They can't be programmed the same way.
  - Guess why Google's Android differs from GNU/Linux ?

- **Back to the Basics !**
  - It's not that more difficult to code in C/C++ than in JS or other "high-level language".
  - It's been proven to work; guess how's been coded your high-level language.
  - Go straight to the point: avoid as many indirection layers as you can.

Backup Slides:
Miscellaneous Tips & Tricks

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Miscellaneous Tips & Tricks (1/2) …

- **Data (De)Serialization:**
  - Consumes a lot of CPU time: avoid at ALL cost whenever possible.
  - Only serialize elements you really need to, not the whole class content.
  - When possible, use shared memory instead.
  - Check serializer routines from the FOSS you include:
    - e.g. qjson adds extra white spaces that make it nice on Wireshark.
    - Our serialized 'contact' object (40 kB) contained 4 kB of white spaces.

- **Logs (seen in so many programs …):**
  - Check log macro level THEN compute log string, and not the opposite:

```
#define LOG(lvl, format, arg...) do { \
  snprintf (fmt, sizeof (fmt), "%s: %s\n", format); \
  va_start (va, format); \
  if (lvl < DEBUG_LEVEL) \
    vfprintf (stderr, fmt, va); \
  va_end (va); \
} while (0);
```

```
#define LOG(lvl, format, arg...) do { \
  if (lvl < DEBUG_LEVEL) \
    snprintf (fmt, sizeof (fmt), "%s: %s\n", format); \
  va_start (va, format); \
  vfprintf (stderr, fmt, va); \
  va_end (va); \
} while (0);
```

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Miscellaneous Tips & Tricks (2/2) …

- **Memory Allocation:**
  - Avoid Memory Fragmentation:
    you'd better keep some objects in memory than continuously (de)allocating them.
  - Real-Time Memory Management:
    for performance critical apps, you'd better use a pre-allocated memory pool, that will never go in page fault (sloooooow).

- **Compiler Optimizations:**
  - GCC can do wonders by adding various optimizations flags (usually –march=…, -Ox, and –mfpu=neon when using floating point on ARM), but it's a tradeoff with portability.
  - Isolate your critical sections code into dedicated C file and use **Acovea** (see http://goo.gl/KdLqK) for determining the best compiler options through evolutionary algorithms.
  - Rewrite your critical sections code using GCC inline ASM (very useful on codec routines).
  - See some FPU calculation on Pandaboard: Go http://goo.gl/hT9Q7 for benchmark sources.

	Measured Execution Time (usec)
C	2730 (reference time)
C with GCC Optimizations -O3 -fomit-frame-pointer -mcpu=cortex-a9 -ftree-vectorize -ffast-math	2594 (1.05x faster)
C with GCC Optimizations and NEON SIMD -mfloat-abi=softfp -mfpu=neon	366 (7.45x faster)
Inline NEON ASM -mfloat-abi=softfp -mfpu=neon	275 (9.9x faster)

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Web Technologies Optimizations (if you _really_ wanna go this way) ...

- **Web Rendering Engine Optimizations:**
  - Tune your rendering engine to use JIT.
  - Tune your rendering engine not to render invisible widgets (off-screen or hidden layers).
  - Tune your rendering engine to have a limited object cache
    (otherwise you'll quickly get low on free memory, which will induce more page faults
    and slow down your whole system until OOM gets its job done).

- **Simplify your CSS:**
  - Use regular images instead of slow CSS transformations.
  - Use solid pattern instead of gradients.
  - Use correct images size instead of software rescaling them each time.
  - E.g: Scroll lists with CSS gradient pattern took 90% CPU while using CSS solid pattern only took 3% in tests.

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Web Technologies Optimizations (if you _really_ wanna go this way) ...

- Parsing HTML is a CPU hog:
  Remove complexity by lowering DOM's depth as much as possible.
- When designing WebServices, you'd better return a lot of information in one call than to proceed with multiple WS calls (anyway, you're asynchronous, right ?)
- Don't refresh your MMI as much as possible, this is a terribly slow operation:
  You'd better wait for all of your data to be ready.
- If you're lucky enough to have a recent engine, try delegating some graphics to GPU through OpenGL/WebGL to provide hardware acceleration.
- Additional JavaScript tips were provided at Oreilly's conference "**How to Make JavaScript Fast**" (see http://goo.gl/K7VYd).

Process as much logic code as possible in C/C++ (i.e. go Native !!)

=> See Google's Chrome NativeClient approach (http://code.google.com/p/nativeclient/).

AT THE SPEED OF IDEAS™

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