P51a - KUtrace

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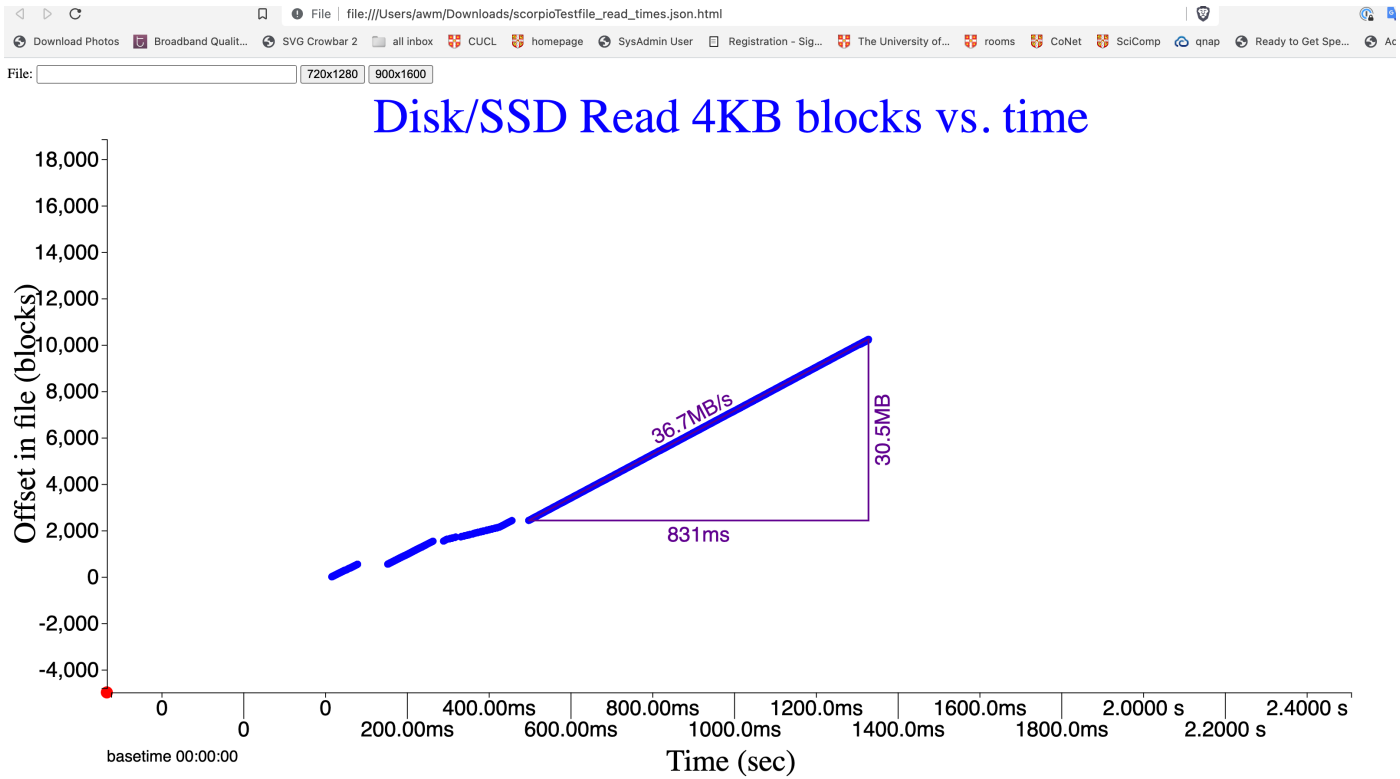
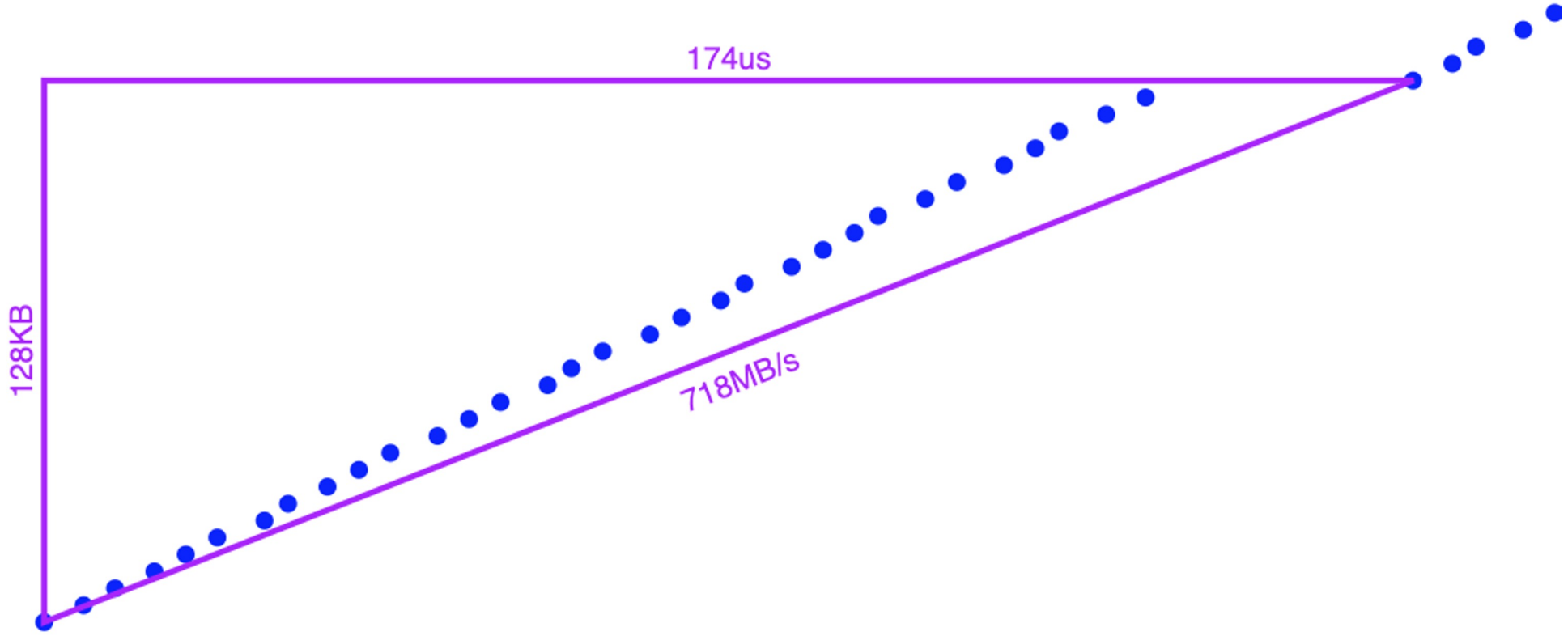
With many slides adapted or stolen from Dick Sites Comp790 material

Disk / time / throughput measuring tool (left shift and drag, it will snap)



HTML: shift-click-drag for measurement triangle



Why are our lives so hard?

- Computers do not behave the way we want them to.
- Multiplexing is both wonderful and a pain
- Quality of service cross-talk
- We don’t have exclusive access to all the things we need
  - If we did – life would be VERY expensive.
- We don’t share well and sometimes….

Many Sources of Interference

- Most interference comes from software
- But a bit from the hardware underpinnings
- In a shared college stairwell, most interference comes from jerky neighbors
- But thin walls and bad kitchen venting maybe the hardware underpinnings

Kernel-user tracing

Recall: Measurement methods

- Trade intrusiveness vs. overhead vs. information vs. complexity
- Trace information in a program is useful.
  - “printf” as debugging tool?
- The kernel (operating system) is a program too….
- KUtrace specifically traces transitions across the KERNEL/USER barrier

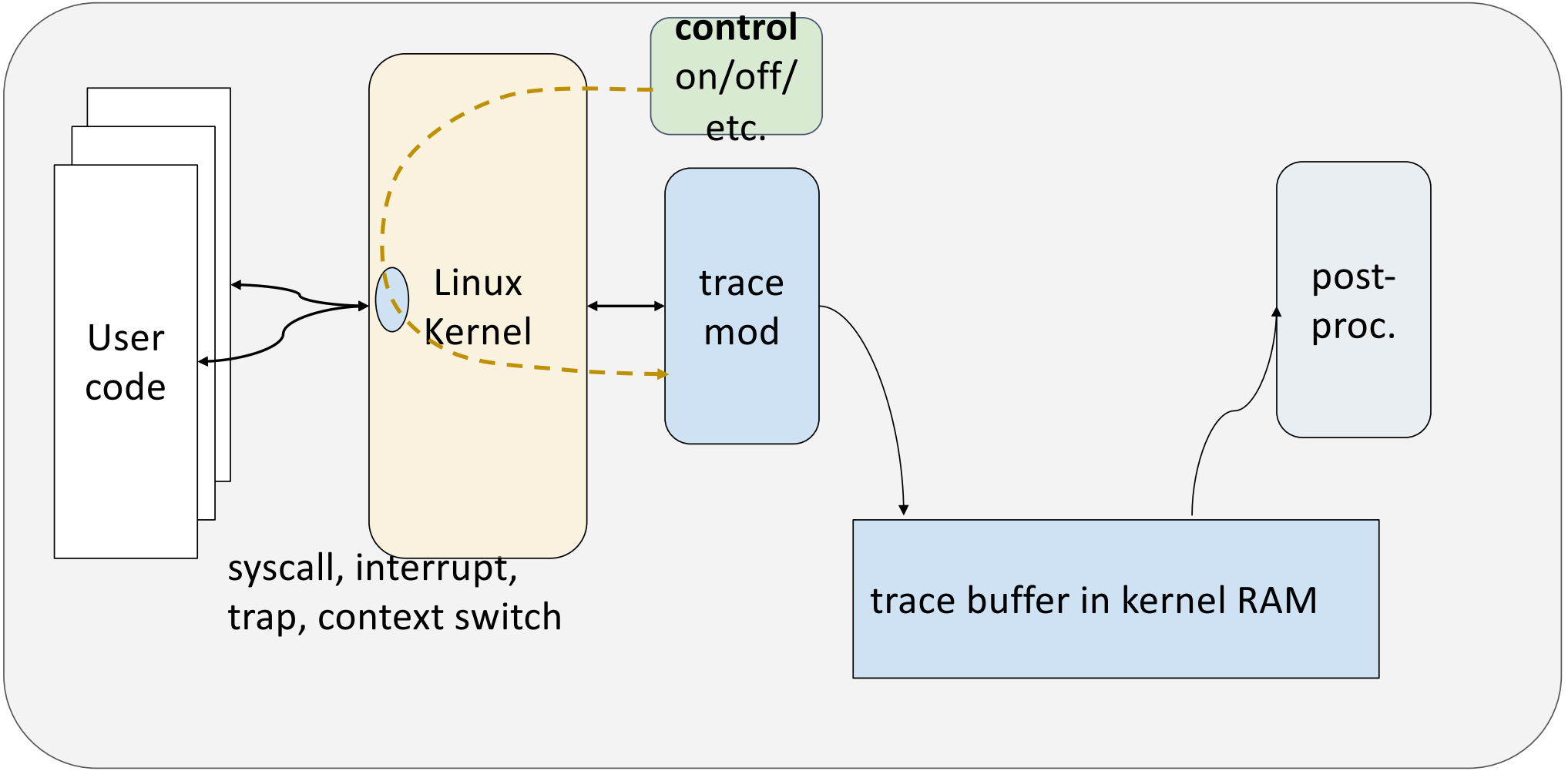
What is KUtrace?

A complete trace of all *transitions* between kernel mode and user mode on all CPU cores of one server machine.

- Minimal events to assign 100% of the CPU time for all cores
- Not so many events that tracing quickly is impractical
- Can be postprocessed into complete timelines

Tracing is the *only* tool that can capture unexpected interactions or interference between programs

Kernel-User implementation


control
on/off/
etc.
User
code
Linux
Kernel
trace
mod
post-
proc.
syscall, interrupt,
trap, context switch
trace buffer in kernel RAM

kutrace_control program

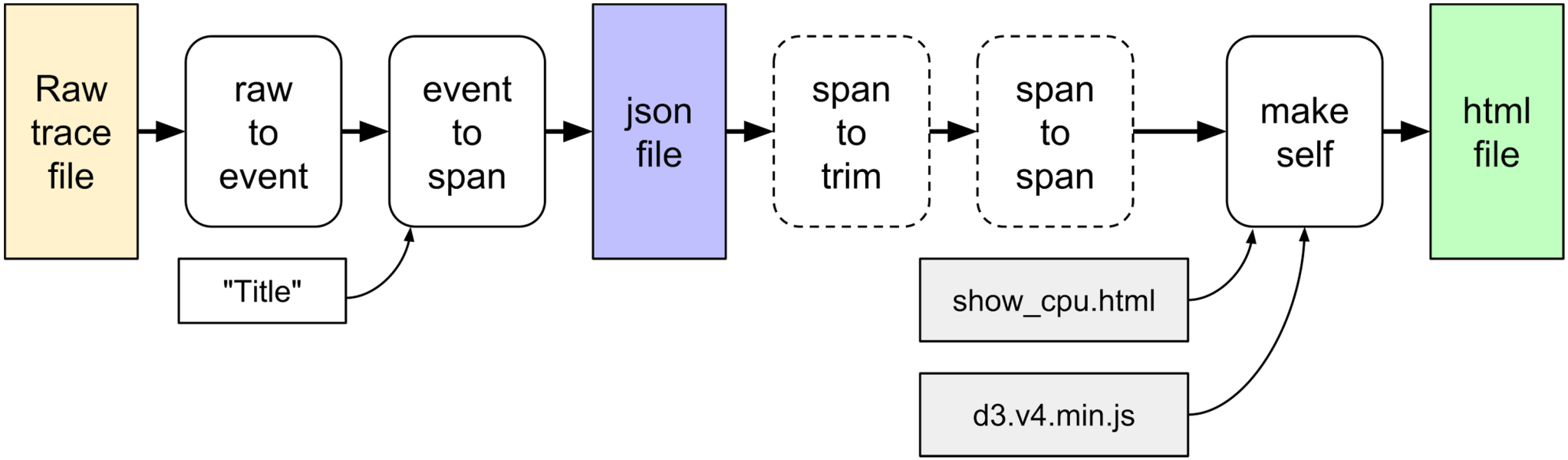
$ ./kutrace_control

> go

> stop

ku_xxxx.trace written

Postprocessing



Postprocessing quick summary

export LC_ALL=C
cat ku_xxxx.trace |./**rawtoevent** | sort -n | ./**eventtospan** "title" | sort > ku_xxxx.json
cat ku_xxxx.json | ./**makeself** show_cpu >ku_xxxx.html
google-chrome ku_xxxx.html

rawtoevent

rawtoevent

Convert raw binary trace file to readable text lines, one per event

- extend timestamps, convert to 10ns increments
  linear interpolation between trace start/end time pairs:
  <gettimeofday, time counter>
- propagate cpu, pid, rpcid
  so every event has each value
- put in names
  so every event has the syscall name, IRQ name, process name, etc.

rawtoevent output sample (text)

```
# [1] 2018-06-24_12:48:58.335301
# T          DUR EVENT CPU PID RPC (10ns time)
  |            |    |    |    |      |  ARG0 RETVAL IPC NAME
  |            |    |    |    |      |  |    |   |    |
5940928129 0 1038 3  10870 0  0 0 13 page_fault (40e)
5940928563 0 1550 3  10870 0  0 0 10 /page_fault (60e)
5940928949 0 2050 3  10870 0  7520 0 13 open (802)
5940929482 0 2562 3  10870 0  0 3 13 /open (a02)          not merged, dur > 255
5940929517 0 2048 3  10870 0  3 0 0 read (800)
5940929761 0 2560 3  10870 0  0 832 2 /read (a00)               not merged, ret > 127
5940929967 59 2053 3  10870 0  3 0 3 fstat (805)          merged call/ret
5940930094 0 2057 3  10870 0  0 0 0 mmap (809) ...
```

Ten event fields

timestsamp Start time for a span in seconds and fractions. For easy correlation with logs and other files, the seconds part be offset from an exact multiple of one minute in the gettimeofday() time domain, rather than starting at zero.

duration Duration of a span in seconds and fractions.

cpu CPU number as a small integer.

pid Process ID (actually thread ID; the kernel calls this "pid"), low 16 bits.

rpcid RPC ID for datacenter work; may be used for anything

event Event number that starts the time span. Values 0-512 are names, markers, and other specials. 512-4096 kernel events system call, interrupt, fault. 64K+pid are user-mode.

Ten event fields

arg0 The low 16 bits of the first argument to a syscall, else 0.

retval For a call/return span, the low 16 bits of the return value. Byte counts, etc. can be considered unsigned. Return codes can be considered signed.

ipc Instructions per cycle, *quantized* via truncation into 4 bits.
Values 0-7 are multiples of 0.125 IPC, i.e. less than one instruction per cycle.
Values 8-11 are 1.0, 1.25, 1.5, and 1.75 IPC.
Values 12-15 are 2.0, 2.5, 3.0, and 3.5+ IPC.

name Name of the kernel routine or user PID (originally from the kernel 16-byte command field per pid). These names come from naming entries in the raw trace itself.

eventtospan

eventtospan

Convert event text file to timespans, formatted as proper JSON

- Start a timespan at each call transition, end it at each return transition
- Run a small stack of pending executions: Before call, push current execution name, after return pop back to previous. This is how we know what is running after each return.
- If a process migrates to a different CPU core, migrate its execution stack also.
- Add synthetic sine waves to indicate coming out of deep sleep
- Add some causality arcs from make-runnable to that process actually running

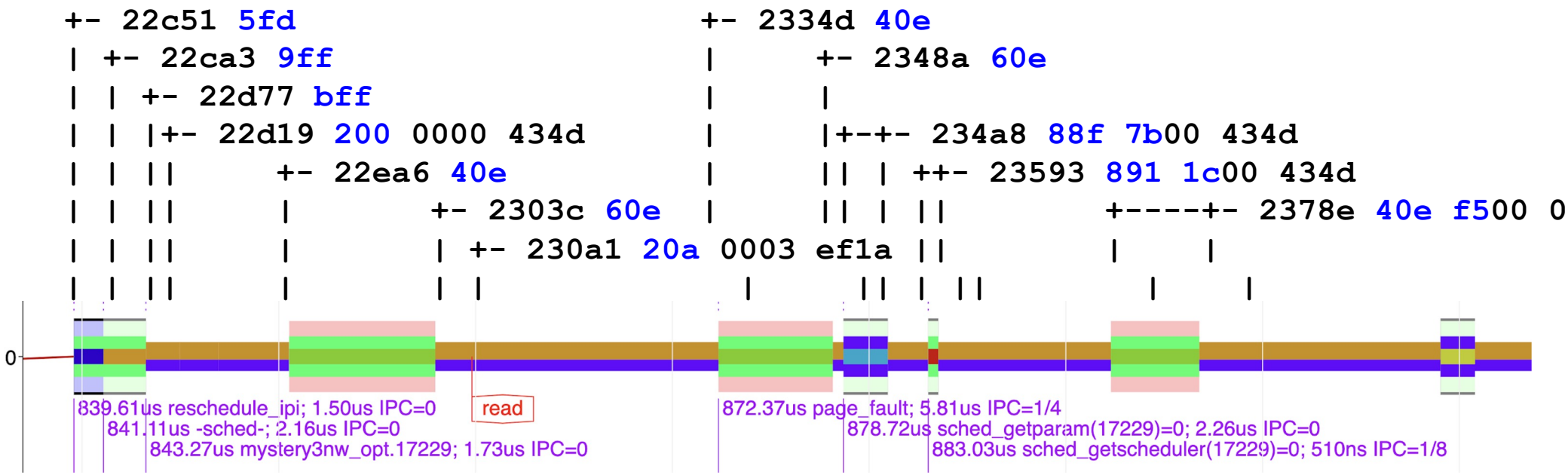
eventtospan output sample (JSON)

```
             # T          DUR  CPU   PID   RPC EVENT
               |            |    |     |     |     | ARG0 RET IPC NAME
               |            |    |     |     |     |    |   |   |     |
[ 59.40928129, 0.00000434, 3, 10870, 0, 1038, 0, 0, 10, "page_fault"],
[ 59.40928563, 0.00000386, 3, 10870, 0, 76406, 0, 0, 13, "bash.10870"],
[ 59.40928949, 0.00000533, 3, 10870, 0, 2050, 7520, 3, 13, "open"],
[ 59.40929482, 0.00000035, 3, 10870, 0, 76406, 0, 3, 0, "bash.10870"],
[ 59.40929517, 0.00000244, 3, 10870, 0, 2048, 3, 832, 2, "read"],
[ 59.40929761, 0.00000206, 3, 10870, 0, 76406, 0, 832, 3, "bash.10870"],
[ 59.40929967, 0.00000059, 3, 10870, 0, 2053, 3, 0, 0, "fstat"],
[ 59.40930026, 0.00000068, 3, 10870, 0, 76406, 0, 832, 0, "bash.10870"],
[ 59.40930094, 0.00000300, 3, 10870, 0, 2057, 0, 12288, 9, "mmap"],
```

Transitions vs. timespans: 12 raw trace entries

```
Time Event delta,ret,arg0
22c51 5fd 0000 0000        reschedule_ipi interrupt
22ca3 9ff 0000 0000        enter scheduler
22d19 200 0000 434d        context switch(17229)
22d77 bff 0000 0000        exit scheduler
22ea6 40e 0000 0000        fault page fault
2303c 60e 0000 0000        faultreturn page fault
230a1 20a 0003 ef1a        mark_a("read")
2334d 40e 0000 0000        fault page fault
2348a 60e 0000 0000        faultreturn page fault
234a8 88f 7b00 434d        syscall+ret sched_getparam
23593 891 1c00 434d        syscall+ret sched_getscheduler
2378e 40e f500 0000        fault+ret page fault
```

Transitions vs. timespans: 12 raw trace entries

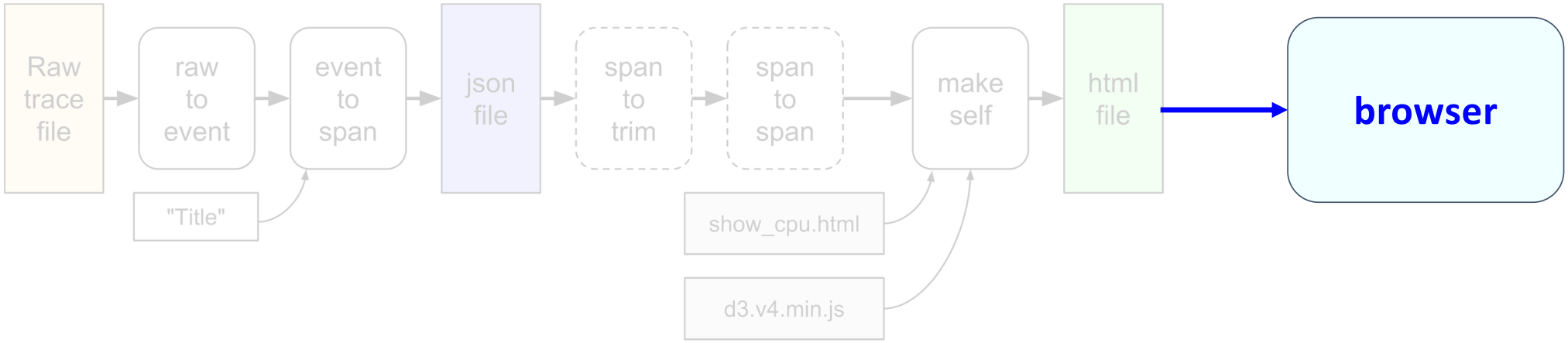


JSON format

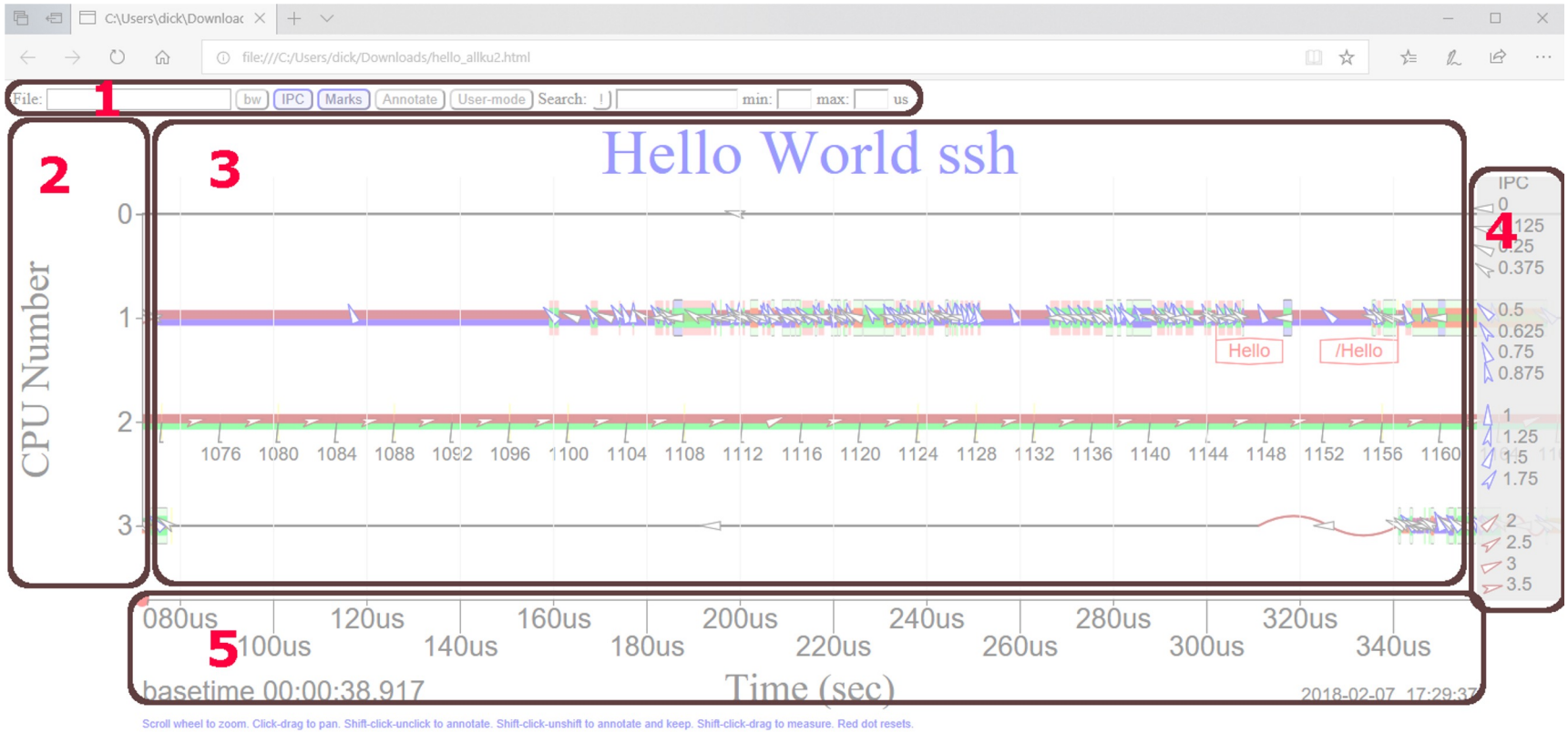
JSON; note leading spaces to sort properly

```
  {
 "Comment" : "V2 with IPC field",
 "axisLabelX" : "Time (sec)",
 "axisLabelY" : "CPU Number",
 "flags" : 128,
 "shortMulX" : 1,
 "shortUnitsX" : "s",
 "thousandsX" : 1000,
 "title" : "Hello World",
 "tracebase" : "2018-01-18_22:54:21",
 "version" : 2,
"events" : [
[ 23.66655382, 0.00000218, 2, 1995, 0, 2055, 59216, 1, 0, "poll"],
   ...
[999.0, 0.0, 0, 0, 0, 0, 0, 0, 0, ""]
]}
```

Postprocessing



KUtrace display of timelines



Play with the html interface

- (on each pi)
- `~/KUtrace/hello_world_demo.json`

and it's

- `~/KUtrace/hello_world_demo.html`

Make a copy to your own machine, display, and play.

Textbook Chapter 19 pp257-266 provide a *manual* for the GUI
The following slides provide insight into the design decisions.

Display issues

Problem:

Possibly 1-10 million execution spans to display

Solutions:

- spantospan reduces granularity, so fewer spans
- spantotrim keeps only a subset time interval, so fewer spans
- HTML initially shows entire trace at modest resolution, allows user to pan and zoom to reveal detail at various different places.
- HTML *elides* spans that are narrower than 1 pixel, combining several until they total at least one pixel. The total is then displayed with a single-color line, not three or four different colors -- just idle or kernel or user.

Display issues

Problem:

Showing different processes or syscalls in different colors is too hard to distinguish -- only about 12-20 distinct colors on screen

Solutions:

- Use pairs of colors, PID mod 15 to pick one, PID mod 17 to pick the other, giving 15x17 = 255 combinations total. Display as two stacked vertical lines.
- For kernel-mode, add third lightened background color to distinguish syscall, interrupt, and fault code.

Display issues

Problem:

Display CPU timelines plus PID timelines plus RPC timelines, but now the vertical dimension is too crowded

Solutions:

- Group the spans: CPU, PID, RPC
- Make groups collapsible, and by default collapse PID and RPC.
- Allow Y-axis to pan and zoom
- Suppress lines whose non-idle content is off-screen
- Allow shift-click on Y-axis labels to highlight one or more only
- Allow shift-click on group labels to collapse un-highlighted rows
- Show vertically narrow spans as single-color lines, to speed up display

Display issues

Problem:

Color-blind users

Solutions:

- Try limited gray-scale combinations of three lines per span -- **fails**
- Try color-Brewer color-blind safe colors http://colorbrewer2.org -- **fails** with not enough distinct colors (about 7-9).
- Equal-luminance and thus low-contrast syscall/IRQ/fault background colors are particularly problematic. So add high-contrast one-pixel edges -- black, gray, white
- Add CB button that simply toggles RGB channels to GBR

Display issues

Problem:

Too many digits in X-axis time labels

Solutions:

- Give overall base (start) time in HH:MM:SS and then just seconds from there on the X-axis.
- When zoomed in, move millisecond digits to base time and just give milliseconds from there on the X-axis.
- When zoomed in further, move millisecond and microsecond digits to base time and just give microseconds from there on the X-axis.
- Change axis **units** to match

More display issues

easy to get lost -- how to get back? -- red button

hard to get overview -- user button to label all processes, just first instance, short names

hard to click on one span at a time to see detail -- all button to label all spans on screen

want to know details about one span -- long label has start time, full name, syscall(arg)=ret, process id, duration, IPC.

Labels overlap -- stack them vertically in ~3 tracks, use semi-opaque white background

labelling all takes forever to display when 1M spans -- at most one label start per pixel location

same with search results

More display issues

easy to lose place after pan/zoom -- retain nearest label and redisplay it after pan/zoom

want grid, but not intrusive -- almost-white vertical grid lines

straight-line wakeup arrows blend into span lines, not visible if overlapping -- curve them

want to search for unusually long or short spans -- usec min/max range

can't find a particular rarely-executed process -- use search by name or pid number

hard to distinguish IPC triangle angles -- color-code groups of four, notch alternate shapes

More display issues

want to see total time for particular spans -- search result gives count and total time

want labels to show which row they label -- put just underneath that row

want to line up labelled items across different rows -- extend solid line below label row, dotted line above

want to determine time between events -- click-drag snaps to event row and start time, giving elapsed time

More display issues

clutter from too many identical PID labels -- only label user-mode once at first time from left edge

clutter from too many marks -- suppress if too close together, button to suppress them all

clutter from IPC triangles -- suppress if too close together or X width is too small, button to suppress them all, off by default

too much clutter with wakeup arcs -- suppress short ones if X width is too small, button to suppress them all

More display issues

in a presentation, want to quickly show specific subsets of a trace -- 1..5 buttons to save/restore pan, zoom, and buttons

fonts too small for presentations -- click title to change font sizes

explain UI without taking much space -- single Usage() line at bottom, with [more} to expand to a screenful of detail