Analysis of randomness levels in the kernel entropy pool after boot

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What we will discuss

1. Pseudo Random Number Generators
2. General Structure
3. Data Collection
4. Data Analysis
5. Future Plans
6. Other Works
7. Bibliography

Pseudo Random Number Generators - Applications

Applications:

- One time pads

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Linux Kernel PRNG

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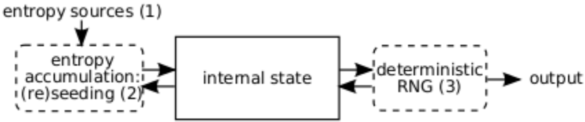
  - User space: `/dev/urandom`
  - Kernel space: `get_random_bytes()`



Entropy sources:

- Timers

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- Hardware input

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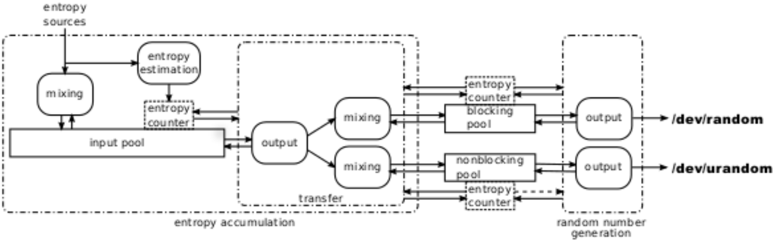
- Timers
- Hardware input
- Hard drives
- Interrupts
- Different hardware devices

General Structure



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Boot process
Input to nonblocking pool:

- add_timer_randomness()
    - add_input_randomness()
    - add_disk_randomness()
- add_interrupt_randomness()

Environment

- Linux kernel version: `3.16.1`

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- Make data available through proc file system
  - (char) large enough buffer to contain the data (200KB)

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  - `proc_create("prng_input", 0, NULL, &prng_input_proc_fops);`

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  - Data pushed to entropy pool
- Make data available through `proc` file system
  - `(char)` large enough buffer to contain the data (200KB)
  - `proc_create("prng_input", 0, NULL, &prng_input_proc_fops);`
  - `proc_create("prng_nonblocking", 0, NULL, &prng_nonblocking_proc_fops);`

Other scripts

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  parsing kernel messages - `dmesg`
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- Script waiting for initialization of the nonblocking pool
  parsing kernel messages - `dmesg`
  store data on drive or over network
- `systemd` service file starting the script at the end of the boot process
- Script for parsing raw rata into separate directories and files
  - input pool
  - nonblocking pool

Different randomness of input data

Target - `add_device_randomness()`

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Two kind of entries:

- Buffer:

```
_mix_pool_bytes(&input_pool, buf, size, NULL);
```

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Target - `add_device_randomness()`
Two kind of entries:

- Buffer:

```
_mix_pool_bytes(&input_pool, buf, size, NULL);
```

- Time information:

```
unsigned long time = random_get_entropy() ^ jiffies;
_mix_pool_bytes(&input_pool, &time, sizeof(time), NULL);
```

add_device_randomness-__dev_open

```
Device information
Static/Predictable data
00000000  06 00 00 00 00 00 00 00  00 00 00 00 00 00 06 00  |................|
00000010  00 00 00 00 00 00 52 54  00 47 9d 3d 06 00 00 00  |......RT.G.=....|
00000020  00 00 00 00 00 00 00 00  00 00 06 00 00 00 00 00  |................|
00000030  00 00 52 54 00 47 9d 3d  06 00 00 00 00 00 00 00  |..RT.G.=........|
00000040  00 00 00 00 00 00 06 00  00 00 00 00 00 00 52 54  |..............RT|
00000050  00 47 9d 3d 06 00 00 00  00 00 00 00 00 00 00 00  |.G.=............|
00000060  00 00 06 00 00 00 00 00  00 00 52 54 00 47 9d 3d  |..........RT.G.=|
00000070  06 00 00 00 00 00 00 00  00 00 00 00 00 00 06 00  |................|
00000080  00 00 00 00 00 00 52 54  00 47 9d 3d 06 00 00 00  |......RT.G.=....|
00000090  00 00 00 00 00 00 00 00  00 00 06 00 00 00 00 00  |................|
000000a0  00 00 52 54 00 47 9d 3d  06 00 00 00 00 00 00 00  |..RT.G.=........|
000000b0  00 00 00 00 00 00 06 00  00 00 00 00 00 00 52 54  |..............RT|
000000c0  00 47 9d 3d 06 00 00 00  00 00 00 00 00 00 00 00  |.G.=............|
000000d0  00 00 06 00 00 00 00 00  00 00 52 54 00 47 9d 3d  |..........RT.G.=|
000000e0  06 00 00 00 00 00 00 00  00 00 00 00 00 00 06 00  |................|
000000f0  00 00 00 00 00 00 52 54  00 47 9d 3d 06 00 00 00  |......RT.G.=....|
```

add_device_randomness-register_netdevice

```
Device information
Static/Predictable data
00000000  06 00 00 00 00 00 00 00  00 00 00 00 00 00 06 00  |................|
00000010  00 00 00 00 00 00 52 54  00 47 9d 3d 06 00 00 00  |......RT.G.=....|
00000020  00 00 00 00 00 00 00 00  00 00 06 00 00 00 00 00  |................|
00000030  00 00 52 54 00 47 9d 3d  06 00 00 00 00 00 00 00  |..RT.G.=........|
00000040  00 00 00 00 00 00 06 00  00 00 00 00 00 00 52 54  |..............RT|
00000050  00 47 9d 3d 06 00 00 00  00 00 00 00 00 00 00 00  |.G.=............|
00000060  00 00 06 00 00 00 00 00  00 00 52 54 00 47 9d 3d  |..........RT.G.=|
00000070  06 00 00 00 00 00 00 00  00 00 00 00 00 00 06 00  |................|
00000080  00 00 00 00 00 00 52 54  00 47 9d 3d 06 00 00 00  |......RT.G.=....|
00000090  00 00 00 00 00 00 00 00  00 00 06 00 00 00 00 00  |................|
000000a0  00 00 52 54 00 47 9d 3d  06 00 00 00 00 00 00 00  |..RT.G.=........|
000000b0  00 00 00 00 00 00 06 00  00 00 00 00 00 00 52 54  |..............RT|
000000c0  00 47 9d 3d 06 00 00 00  00 00 00 00 00 00 00 00  |.G.=............|
000000d0  00 00 06 00 00 00 00 00  00 00 52 54 00 47 9d 3d  |..........RT.G.=|
000000e0  06 00 00 00 00 00 00 00  00 00 00 00 00 00 06 00  |................|
000000f0  00 00 00 00 00 00 52 54  00 47 9d 3d 06 00 00 00  |......RT.G.=....|
```

add_device_randomness-usb_new_device

Device information

Static/Predictable data

```
00000000  0c 00 00 00 00 00 00 00  30 30 30 30 3a 30 30 3a  |........0000:00:|
00000010  30 35 2e 37 14 00 00 00  00 00 00 00 45 48 43 49  |05.7........EHCI|
00000020  20 48 6f 73 74 20 43 6f  6e 74 72 6f 6c 6c 65 72  | Host Controller|
00000030  28 00 00 00 00 00 00 00  4c 69 6e 75 78 20 33 2e  |(.......Linux 3.|
00000040  31 36 2e 31 2d 74 68 73  2d 67 33 36 66 31 37 66  |16.1-ths-g36f17f|
00000050  30 2d 64 69 72 74 79 20  65 68 63 69 5f 68 63 64  |0-dirty ehci_hcd|
00000060  0c 00 00 00 00 00 00 00  30 30 30 30 3a 30 30 3a  |........0000:00:|
00000070  30 35 2e 30 14 00 00 00  00 00 00 00 55 48 43 49  |05.0........UHCI|
00000080  20 48 6f 73 74 20 43 6f  6e 74 72 6f 6c 6c 65 72  | Host Controller|
00000090  28 00 00 00 00 00 00 00  4c 69 6e 75 78 20 33 2e  |(.......Linux 3.|
000000a0  31 36 2e 31 2d 74 68 73  2d 67 33 36 66 31 37 66  |16.1-ths-g36f17f|
000000b0  30 2d 64 69 72 74 79 20  75 68 63 69 5f 68 63 64  |0-dirty uhci_hcd|
000000c0  0c 00 00 00 00 00 00 00  30 30 30 30 3a 30 30 3a  |........0000:00:|
000000d0  30 35 2e 31 14 00 00 00  00 00 00 00 55 48 43 49  |05.1........UHCI|
000000e0  20 48 6f 73 74 20 43 6f  6e 74 72 6f 6c 6c 65 72  | Host Controller|
000000f0  28 00 00 00 00 00 00 00  4c 69 6e 75 78 20 33 2e  |(.......Linux 3.|
```

add_device_randomness-dmi_walk_early

```
Device information
Static/Predictable data
00000000  07 01 00 00 00 00 00 00  00 18 00 00 01 02 00 e8  |................|
00000010  03 00 08 00 00 00 00 00  00 00 00 04 01 00 ff ff  |................|
00000020  42 6f 63 68 73 00 42 6f  63 68 73 00 30 31 2f 30  |Bochs.Bochs.01/0|
00000030  31 2f 32 30 31 31 00 00  01 1b 00 01 01 02 00 00  |1/2011..........|
00000040  64 51 0b d0 d5 29 4b b1  95 b9 ad 20 52 4d 31 f3  |dQ...)K.... RM1.|
00000050  06 00 00 42 6f 63 68 73  00 42 6f 63 68 73 00 00  |...Bochs.Bochs..|
00000060  03 14 00 03 01 01 00 00  00 03 03 03 02 00 00 00  |................|
00000070  00 00 00 00 42 6f 63 68  73 00 00 04 20 01 04 01  |....Bochs... ...|
00000080  03 01 02 a1 06 02 00 fd  fb 8b 07 00 00 00 00 d0  |................|
00000090  07 d0 07 41 01 ff ff ff  ff ff ff 43 50 55 20 31  |...A.......CPU 1|
000000a0  00 42 6f 63 68 73 00 00  10 0f 00 10 01 03 06 00  |.Bochs..........|
000000b0  00 20 00 fe ff 01 00 00  00 11 15 00 11 00 10 02  |. ..............|
000000c0  03 40 00 40 00 00 08 09  00 01 00 07 00 00 44 49  |.@.@..........DI|
000000d0  4d 4d 20 30 00 00 13 0f  00 13 00 00 00 00 ff ff  |MM 0............|
000000e0  1f 00 00 10 01 00 00 14  13 00 14 00 00 00 00 ff  |................|
000000f0  ff 1f 00 00 11 00 13 01  00 00 00 00 20 0b 00 20  |............ .. |
```

add_device_randomness-posix_cpu_timers_exit

```
Device information
Possibly random data
00000000  08 00 00 00 00 00 00 00  88 19 00 00 00 00 00 00  |................|
00000010  08 00 00 00 00 00 00 00  da 0c 00 00 00 00 00 00  |................|
00000020  08 00 00 00 00 00 00 00  c0 09 00 00 00 00 00 00  |................|
00000030  08 00 00 00 00 00 00 00  f0 08 00 00 00 00 00 00  |................|
00000040  08 00 00 00 00 00 00 00  6a 08 00 00 00 00 00 00  |........j.......|
00000050  08 00 00 00 00 00 00 00  3b 09 00 00 00 00 00 00  |........;.......|
00000060  08 00 00 00 00 00 00 00  f3 08 00 00 00 00 00 00  |................|
00000070  08 00 00 00 00 00 00 00  ca 08 00 00 00 00 00 00  |................|
00000080  08 00 00 00 00 00 00 00  bb 08 00 00 00 00 00 00  |................|
00000090  08 00 00 00 00 00 00 00  32 09 00 00 00 00 00 00  |........2.......|
000000a0  08 00 00 00 00 00 00 00  a8 08 00 00 00 00 00 00  |................|
000000b0  08 00 00 00 00 00 00 00  f6 09 00 00 00 00 00 00  |................|
000000c0  08 00 00 00 00 00 00 00  56 09 00 00 00 00 00 00  |........V.......|
000000d0  08 00 00 00 00 00 00 00  1a 09 00 00 00 00 00 00  |................|
000000e0  08 00 00 00 00 00 00 00  cf 08 00 00 00 00 00 00  |................|
000000f0  08 00 00 00 00 00 00 00  db 08 00 00 00 00 00 00  |................|
```

Closer look - posix cpu timers exit

Statistics:

- # of entries: 932923
- # of entry classes: 655493
- # of classes / # of entries ratio: 0.702
- average # of 0x00 per entry: 5.155
- lengths of entries: 8B

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`Gather more data to compute Shannons entropy`

- $2^{8*3} = 16777216$

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- $2^{8*3} = 16777216$
- $H(X) = -\sum_i P(x_i) \log_b P(x_i)$

add_device_randomness_time-__dev_open

```
Time information
00000000  08 00 00 00 00 00 00 00  6a d6 be b9 04 00 00 00  |........j.......|
00000010  08 00 00 00 00 00 00 00  4c 7a 00 e0 06 00 00 00  |........Lz......|
00000020  08 00 00 00 00 00 00 00  3d 9b 54 bf 04 00 00 00  |........=.T.....|
00000030  08 00 00 00 00 00 00 00  f6 bf e1 7f 06 00 00 00  |................|
00000040  08 00 00 00 00 00 00 00  a1 4f 56 cb 04 00 00 00  |.........OV.....|
00000050  08 00 00 00 00 00 00 00  f4 98 a0 b7 06 00 00 00  |................|
00000060  08 00 00 00 00 00 00 00  9f 26 d9 a7 04 00 00 00  |.........&......|
00000070  08 00 00 00 00 00 00 00  47 5e 47 cc 06 00 00 00  |........G^G.....|
00000080  08 00 00 00 00 00 00 00  f5 ae 9d db 04 00 00 00  |................|
00000090  08 00 00 00 00 00 00 00  fb cb 3d 06 05 00 00 00  |..........=.....|
000000a0  08 00 00 00 00 00 00 00  bc 19 25 df 04 00 00 00  |..........%.....|
000000b0  08 00 00 00 00 00 00 00  36 52 ff e5 06 00 00 00  |........6R......|
000000c0  08 00 00 00 00 00 00 00  23 cb 13 dd 04 00 00 00  |........#.......|
000000d0  08 00 00 00 00 00 00 00  57 02 0e e7 06 00 00 00  |........W.......|
000000e0  08 00 00 00 00 00 00 00  3a a3 39 d5 04 00 00 00  |........:.9.....|
000000f0  08 00 00 00 00 00 00 00  c7 35 ab db 06 00 00 00  |.........5......|
```

add_device_randomness_time-register_netdevice

```
Time information
00000000  08 00 00 00 00 00 00 00  a9 9b 9e 55 03 00 00 00  |...........U....|
00000010  08 00 00 00 00 00 00 00  30 20 98 3d 03 00 00 00  |........0 .=....|
00000020  08 00 00 00 00 00 00 00  31 47 90 75 03 00 00 00  |........1G.u....|
00000030  08 00 00 00 00 00 00 00  82 70 6c 5d 03 00 00 00  |.........pl]....|
00000040  08 00 00 00 00 00 00 00  5a 01 bd 62 03 00 00 00  |........Z..b....|
00000050  08 00 00 00 00 00 00 00  38 77 97 4a 03 00 00 00  |........8w.J....|
00000060  08 00 00 00 00 00 00 00  c0 4e 41 5d 03 00 00 00  |.........NA]....|
00000070  08 00 00 00 00 00 00 00  4a 10 f2 44 03 00 00 00  |........J..D....|
00000080  08 00 00 00 00 00 00 00  39 28 cc 6e 03 00 00 00  |........9(.n....|
00000090  08 00 00 00 00 00 00 00  47 a5 bf 56 03 00 00 00  |........G..V....|
000000a0  08 00 00 00 00 00 00 00  50 d4 ac 75 03 00 00 00  |........P..u....|
000000b0  08 00 00 00 00 00 00 00  36 60 de 5d 03 00 00 00  |........6‘.]....|
000000c0  08 00 00 00 00 00 00 00  98 3c 95 74 03 00 00 00  |.........<.t....|
000000d0  08 00 00 00 00 00 00 00  bc 9c 96 5c 03 00 00 00  |...........\....|
000000e0  08 00 00 00 00 00 00 00  d3 bf c3 6b 03 00 00 00  |...........k....|
000000f0  08 00 00 00 00 00 00 00  3b fe 8d 53 03 00 00 00  |........;..S....|
```

add_device_randomness_time-usb_new_device

```
Time information
00000000  08 00 00 00 00 00 00 00  a8 0f c0 2f 03 00 00 00  |.........../....|
00000010  08 00 00 00 00 00 00 00  18 1e c0 2f 03 00 00 00  |.........../....|
00000020  08 00 00 00 00 00 00 00  48 68 c0 2f 03 00 00 00  |........Hh./....|
00000030  08 00 00 00 00 00 00 00  72 46 bb 2e 03 00 00 00  |........rF......|
00000040  08 00 00 00 00 00 00 00  63 54 bb 2e 03 00 00 00  |........cT......|
00000050  08 00 00 00 00 00 00 00  10 5c bb 2e 03 00 00 00  |.........\......|
00000060  08 00 00 00 00 00 00 00  bb e8 ed 2d 03 00 00 00  |...........-....|
00000070  08 00 00 00 00 00 00 00  4d f5 ed 2d 03 00 00 00  |........M..-....|
00000080  08 00 00 00 00 00 00 00  24 fd ed 2d 03 00 00 00  |........$..-....|
00000090  08 00 00 00 00 00 00 00  89 dc ca 2c 03 00 00 00  |...........,....|
000000a0  08 00 00 00 00 00 00 00  39 29 ca 2c 03 00 00 00  |........9).,....|
000000b0  08 00 00 00 00 00 00 00  a9 32 ca 2c 03 00 00 00  |.........2.,....|
000000c0  08 00 00 00 00 00 00 00  d8 6a 70 e2 04 00 00 00  |.........jp.....|
000000d0  08 00 00 00 00 00 00 00  28 76 70 e2 04 00 00 00  |........(vp.....|
000000e0  08 00 00 00 00 00 00 00  40 7e 70 e2 04 00 00 00  |........@~p.....|
000000f0  08 00 00 00 00 00 00 00  54 17 81 50 03 00 00 00  |........T..P....|
```

add_device_randomness_time-dmi_walk_early

Time information

```
00000000  08 00 00 00 00 00 00 00  af ba e4 90 03 00 00 00  |................|
00000010  08 00 00 00 00 00 00 00  3e d8 e4 90 03 00 00 00  |........>.......|
00000020  08 00 00 00 00 00 00 00  57 05 e4 90 03 00 00 00  |........W.......|
00000030  08 00 00 00 00 00 00 00  82 69 e3 af 03 00 00 00  |.........i......|
00000040  08 00 00 00 00 00 00 00  a3 87 e0 af 03 00 00 00  |................|
00000050  08 00 00 00 00 00 00 00  ad f3 e0 af 03 00 00 00  |................|
00000060  08 00 00 00 00 00 00 00  74 67 29 9d 03 00 00 00  |........tg).....|
00000070  08 00 00 00 00 00 00 00  2d 85 26 9d 03 00 00 00  |........-.&.....|
00000080  08 00 00 00 00 00 00 00  25 f1 26 9d 03 00 00 00  |........%.&.....|
00000090  08 00 00 00 00 00 00 00  53 eb 67 98 03 00 00 00  |........S.g.....|
000000a0  08 00 00 00 00 00 00 00  d2 07 67 98 03 00 00 00  |..........g.....|
000000b0  08 00 00 00 00 00 00 00  41 73 67 98 03 00 00 00  |........Asg.....|
000000c0  08 00 00 00 00 00 00 00  e9 67 2b a9 03 00 00 00  |.........g+.....|
000000d0  08 00 00 00 00 00 00 00  34 85 28 a9 03 00 00 00  |........4.(.....|
000000e0  08 00 00 00 00 00 00 00  6b f1 28 a9 03 00 00 00  |........k.(.....|
000000f0  08 00 00 00 00 00 00 00  66 9f 8d af 03 00 00 00  |........f.......|
```

add_device_randomness_time-posix_cpu_timers_exit

```
Time information
00000000  08 00 00 00 00 00 00 00  f5 cb 72 4b 03 00 00 00  |..........rK....|
00000010  08 00 00 00 00 00 00 00  2d a0 73 4b 03 00 00 00  |........-.sK....|
00000020  08 00 00 00 00 00 00 00  a5 c8 73 4b 03 00 00 00  |..........sK....|
00000030  08 00 00 00 00 00 00 00  bd 6a 73 4b 03 00 00 00  |.........jsK....|
00000040  08 00 00 00 00 00 00 00  51 96 70 4b 03 00 00 00  |........Q.pK....|
00000050  08 00 00 00 00 00 00 00  01 39 70 4b 03 00 00 00  |.........9pK....|
00000060  08 00 00 00 00 00 00 00  51 59 70 4b 03 00 00 00  |........QYpK....|
00000070  08 00 00 00 00 00 00 00  95 fb 71 4b 03 00 00 00  |..........qK....|
00000080  08 00 00 00 00 00 00 00  f9 1b 71 4b 03 00 00 00  |..........qK....|
00000090  08 00 00 00 00 00 00 00  81 86 6e 4b 03 00 00 00  |..........nK....|
000000a0  08 00 00 00 00 00 00 00  fd 2c 6e 4b 03 00 00 00  |.........,nK....|
000000b0  08 00 00 00 00 00 00 00  f9 56 6e 4b 03 00 00 00  |.........VnK....|
000000c0  08 00 00 00 00 00 00 00  19 fd 6f 4b 03 00 00 00  |..........oK....|
000000d0  08 00 00 00 00 00 00 00  b5 1d 6f 4b 03 00 00 00  |..........oK....|
000000e0  08 00 00 00 00 00 00 00  31 96 6c 4b 03 00 00 00  |........1.lK....|
000000f0  08 00 00 00 00 00 00 00  75 05 6c 4b 03 00 00 00  |........u.lK....|
```

Closer look

Statistics

add_device_randomness_time-__dev_open

- # of entries: 6136
- # of entry classes: 6136
- # of classes / # of entries ratio: 1.0
- avg # of 0x00 per entry: 3.0151
- lengths of entries: 8B

add_device_randomness_time-register_netdevice

- # of entries: 6136
- # of entry classes: 6136
- # of classes / # of entries ratio: 1.0
- avg # of 0x00 per entry: 3.0106
- lengths of entries: 8B

Closer look

Statistics

add_device_randomness_time-usb_new_device

- # of entries: 46020
- # of entry classes: 46018
- # of classes / # of entries ratio: 0.99996
- avg # of 0x00 per entry: 3.0279
- lengths of entries: 8B

add_device_randomness_time-posix_cpu_timers_exit

- # of entries: 932923
- # of entry classes: 932878
- # of classes / # of entries ratio: 0.99995
- avg # of 0x00 per entry: 3.0154
- lengths of entries: 8B

Graph

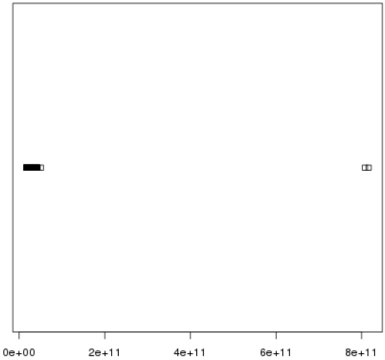

Figure: add_device_randomness_time-__dev_open

Graph

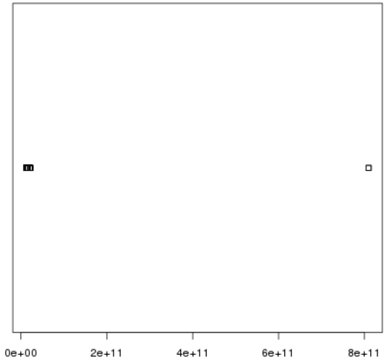

Figure: add_device_randomness_time-register_netdevice

Graph

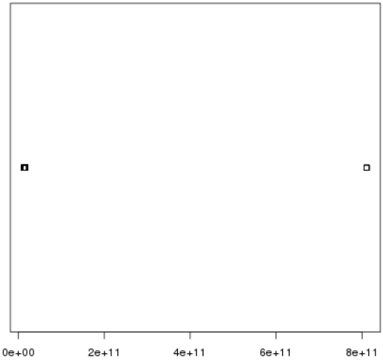

Figure: add_device_randomness-dmi_walk_early

Graph

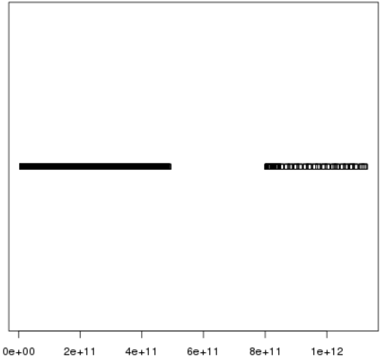

Figure: add_device_randomness_time-posix_cpu_timers_exit

Graph

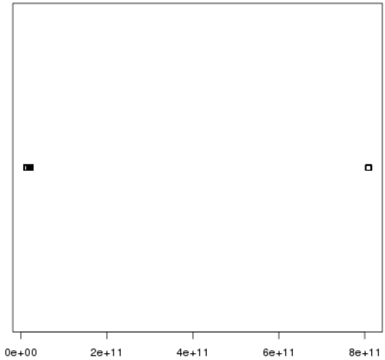

Figure: add_device_randomness_time-usb_new_device

Graph

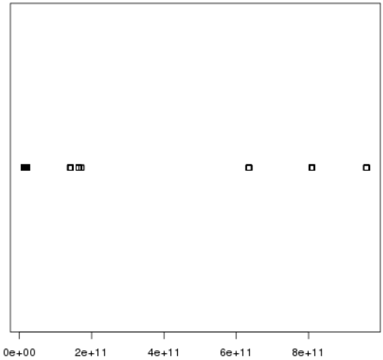

Figure: add_device_randomness_time-usb_new_device

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- GNU rng-tools

Other Works

- Filip Škola - Bachelor thesis
- Ondřej Mokoš - Master thesis

Thanks

Thank you for your attention.

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