Correct, Fast, Maintainable: Choose Any Three!

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Bernard Blackham and Gernot Heiser

NICTA and University of New South Wales
Sydney, Australia

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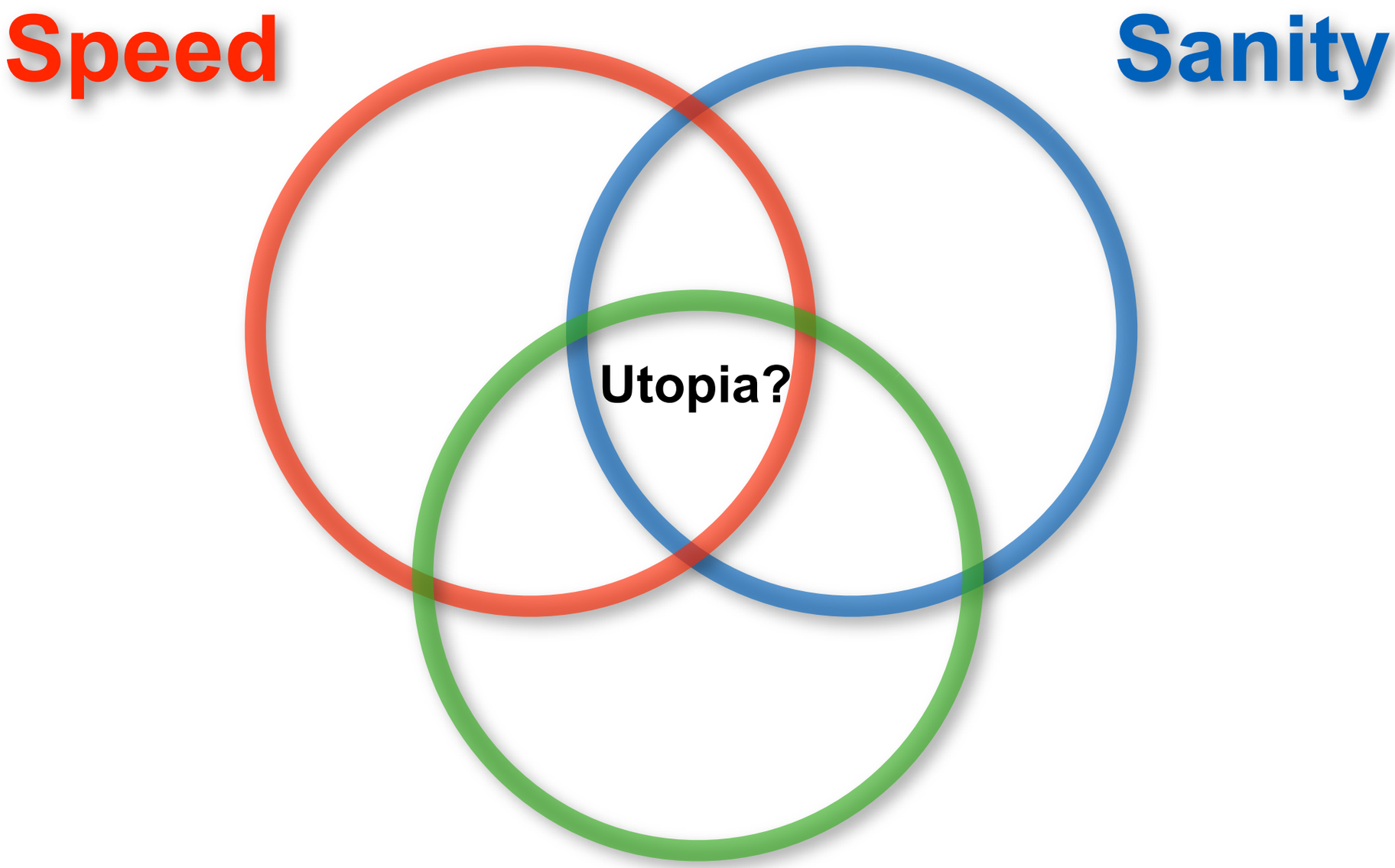
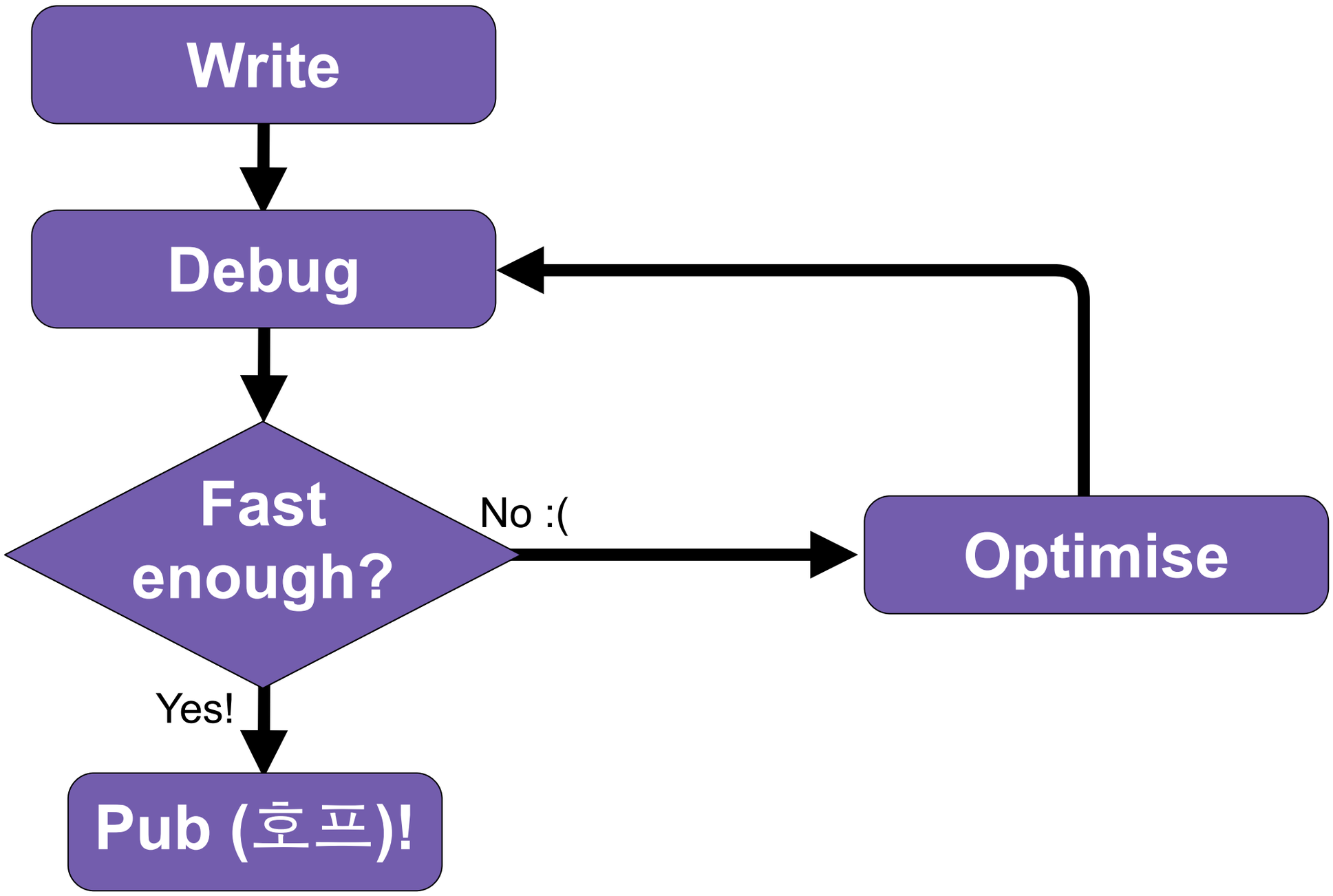
What programmers want



What programmers do



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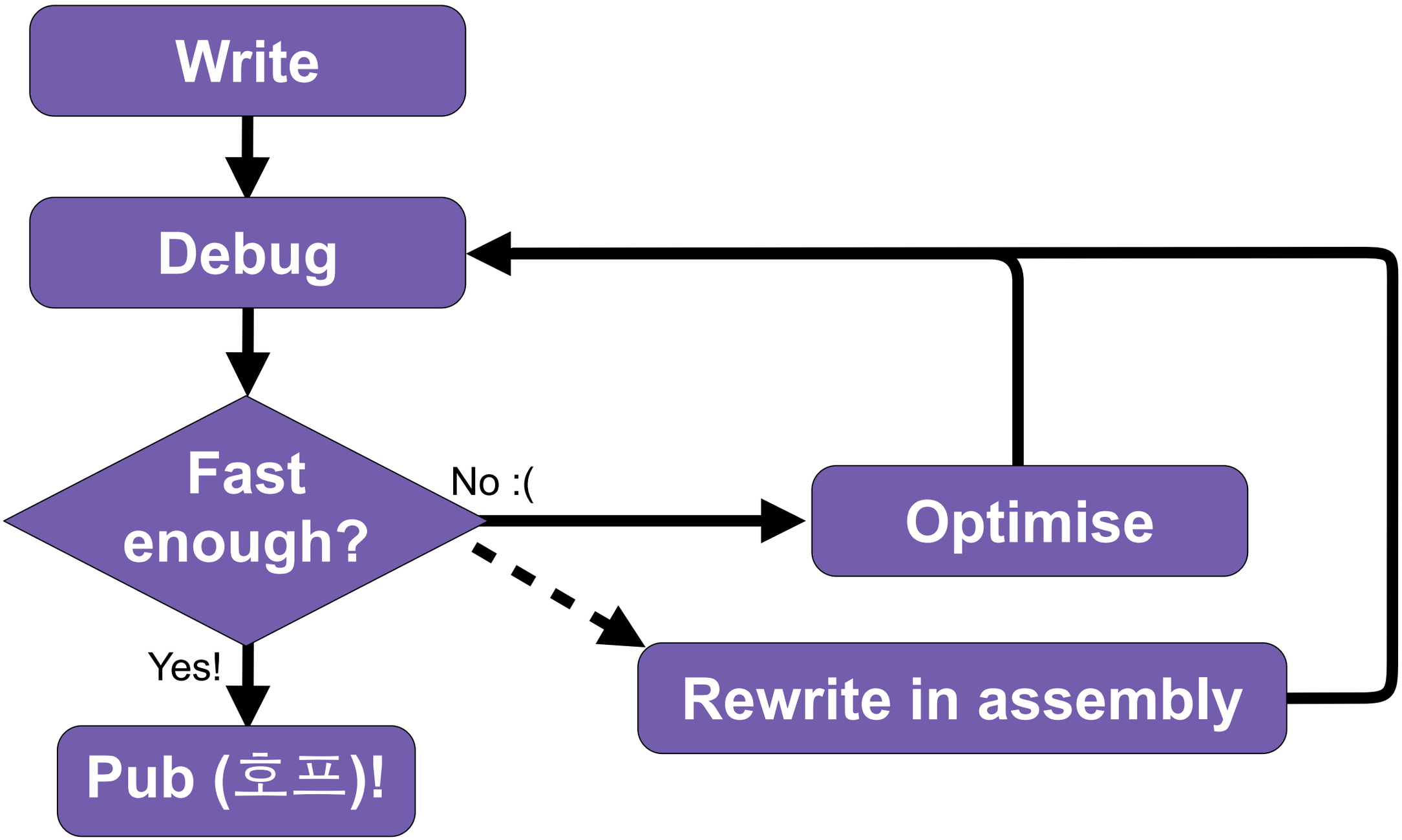

When to use assembly?

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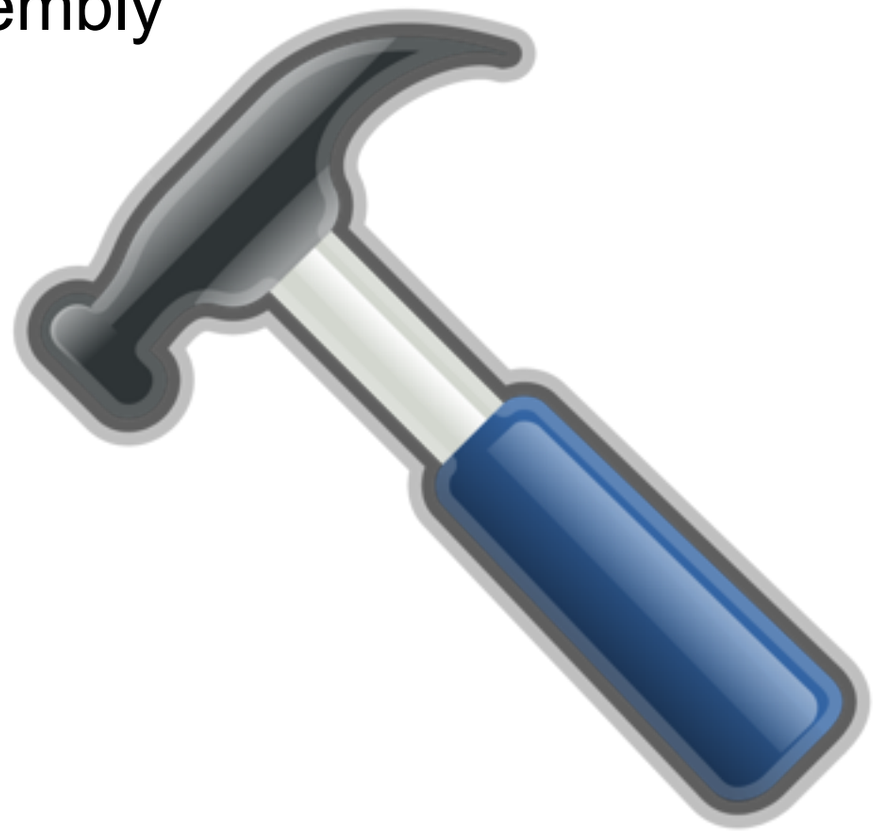
Programmers (should) use assembly as as last resort when:

- higher level languages are not sufficient
- they have the know-how to do better in assembly
- they have little mercy for those who follow



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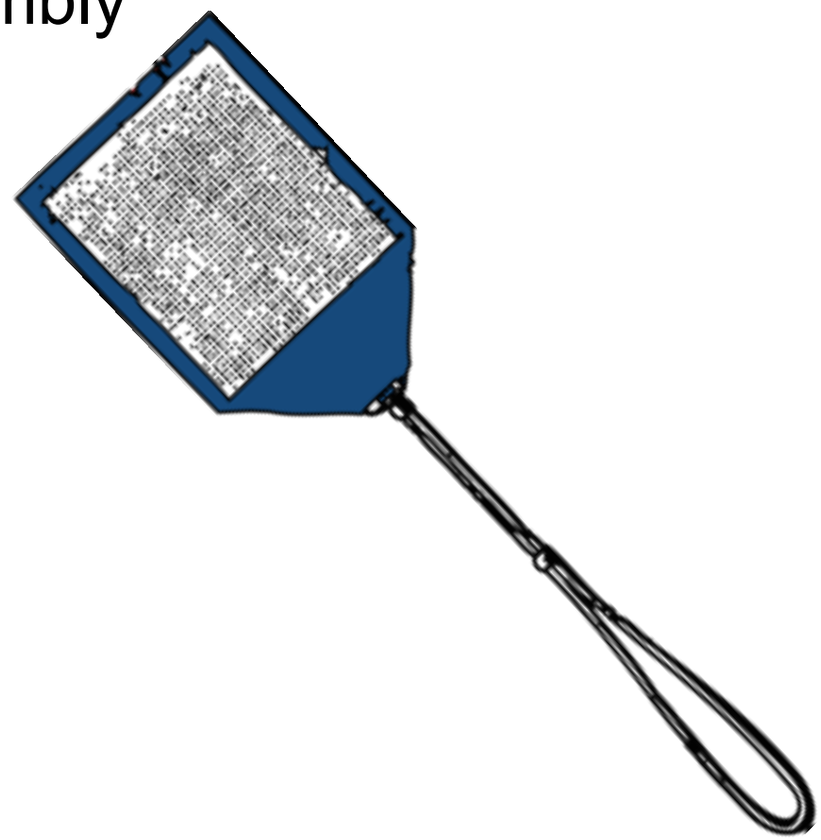

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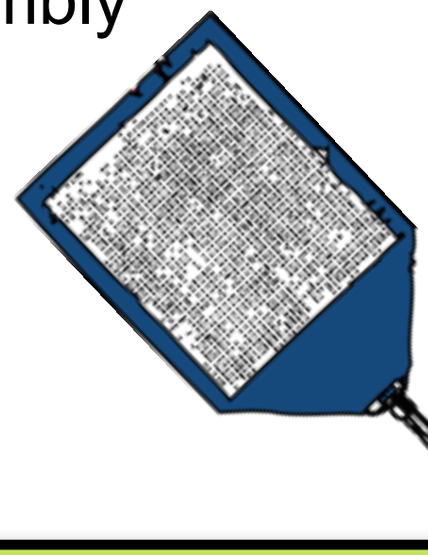

We claim:

- Modern compilers are often smarter than we think
- Many assembly optimisation techniques can be performed in C

A brief history of L4...

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- L4 microkernels emphasise ***fast*** IPC message-passing

> - IPC performance is the Master
>
> Anything which may lead to higher IPC performance has to be discussed.
>
> In case of doubt, decisions in favour of IPC have to be taken.
>
> – Jochen Liedtke (1993)

A brief history of L4...

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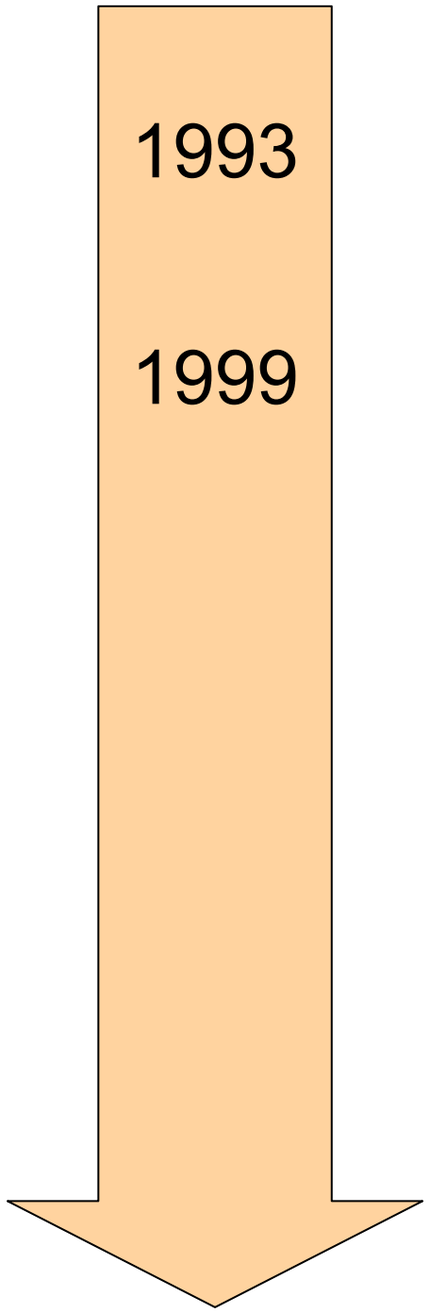
1993 First L4 kernel written entirely in assembly

1999 L4Ka::Hazelnut written in C/C++
IPC *fastpaths* hand-coded in assembly



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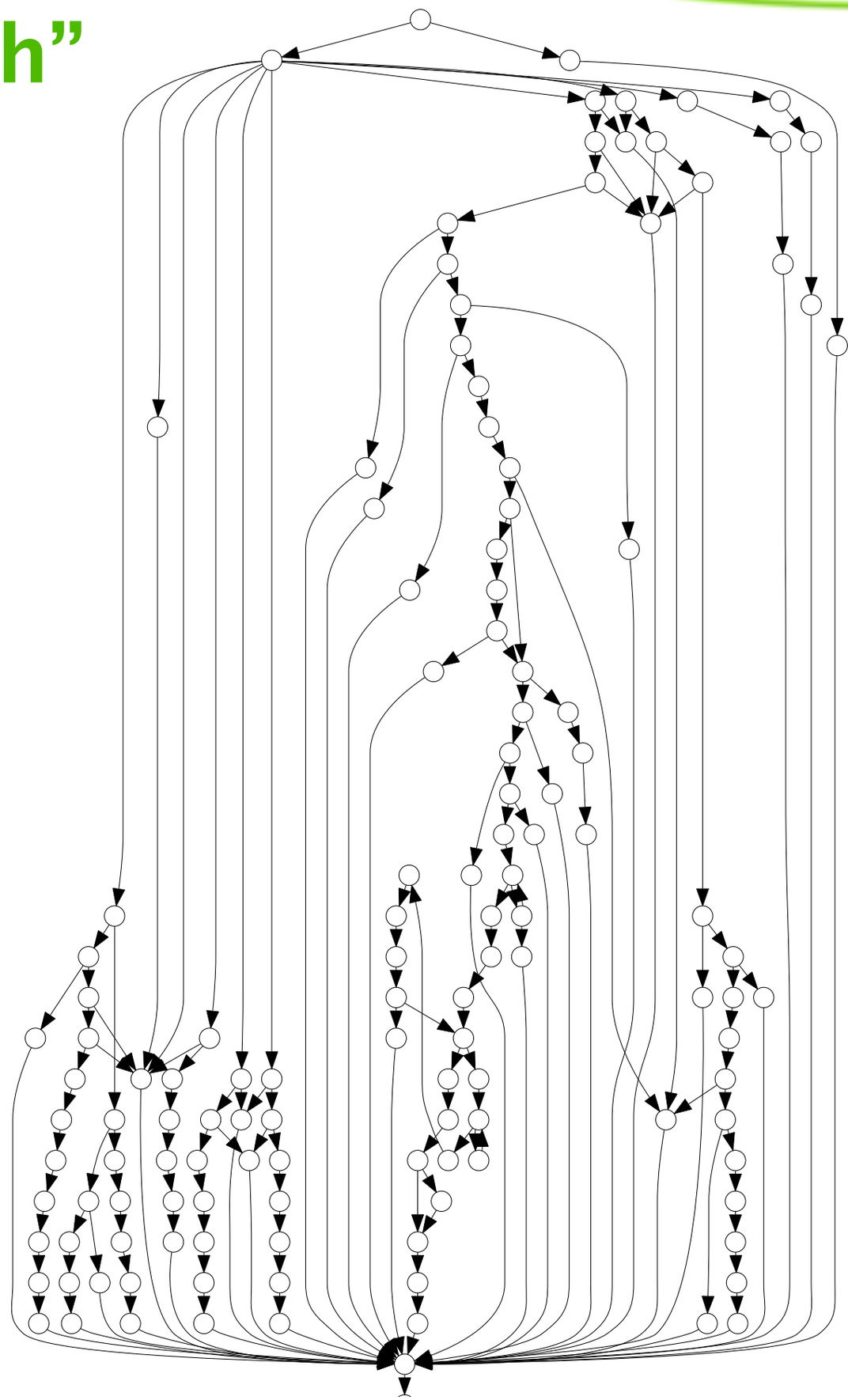
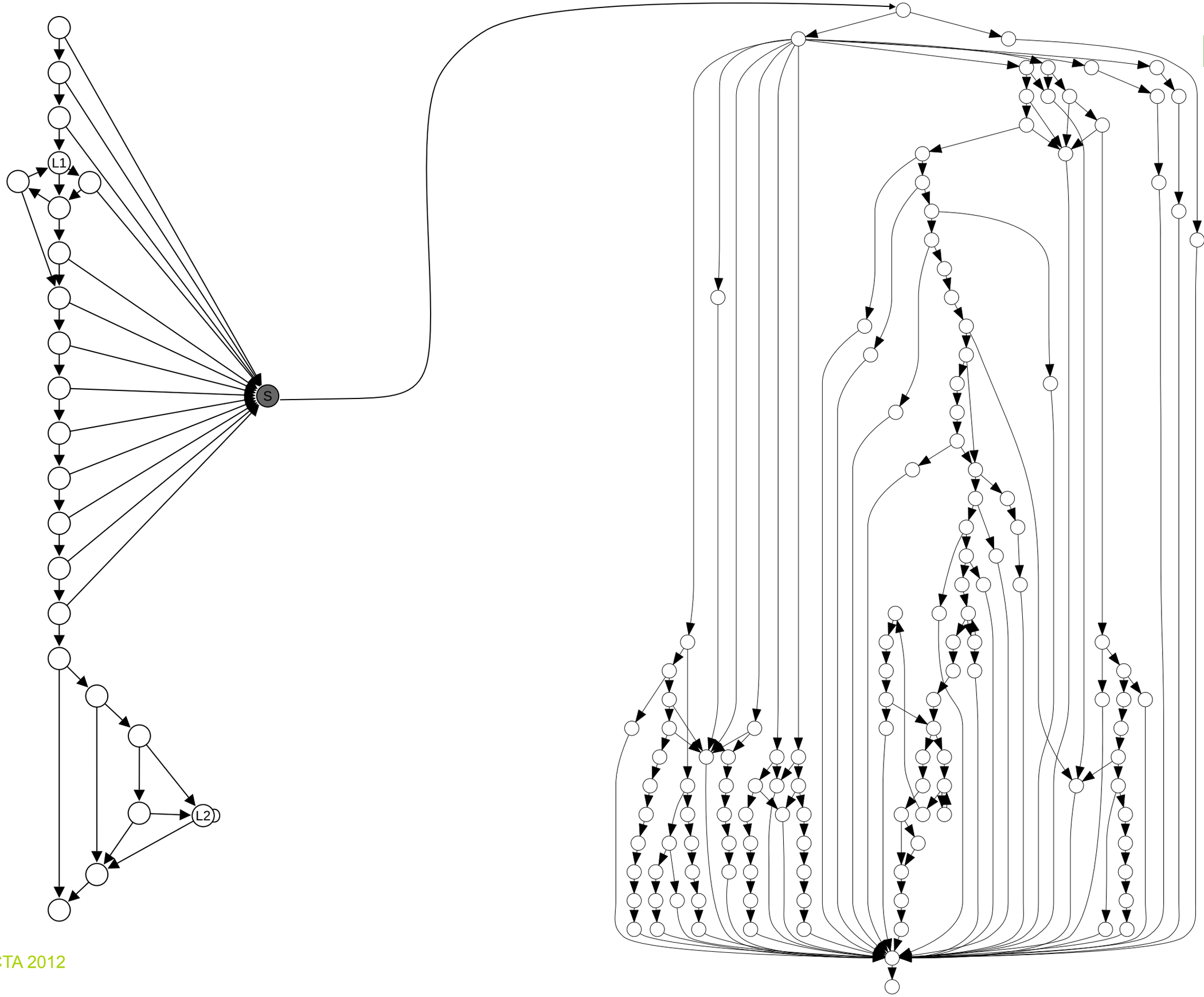
Fastpaths: dedicated code path that optimises the common-case

The “slowpath”





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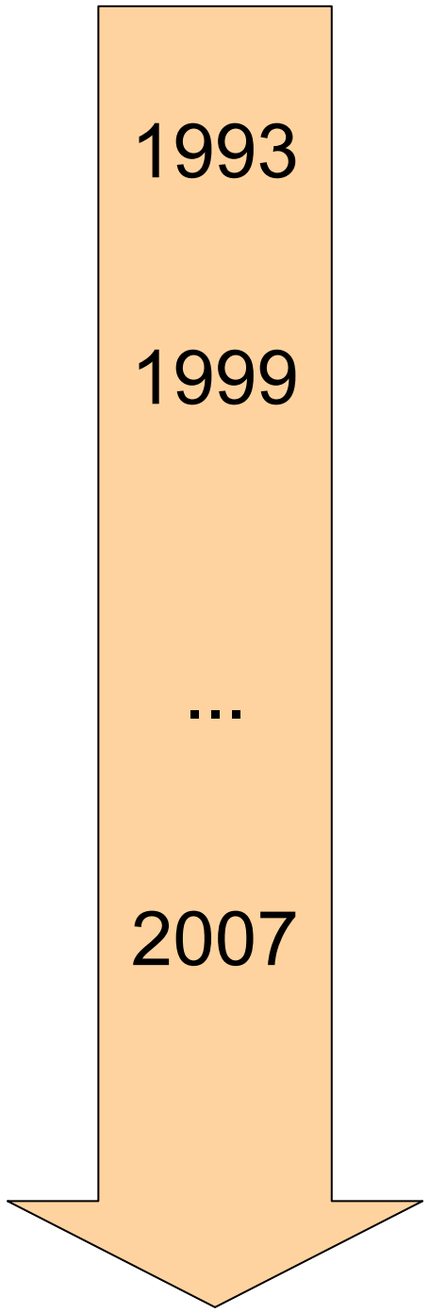

1993 — First L4 kernel written entirely in assembly

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... — More L4 µ-kernels, all C/C++ with fastpaths in assembly

2007 — seL4 implementation written in C
IPC fastpaths written in C

A brief history of L4...

How much performance does a fastpath in C compromise over a fastpath in assembly?

2007

seL4 implementation written in C
IPC fastpaths written in C

How to optimise C code?

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Determine correspondence between C and assembly:

```
void
fastpath_call(word_t cptr, word_t msgInfo)
{
    message_info_t info = message_info_set_msgCapsUnwrapped(
            messageInfoFromWord_nolencheck(msgInfo), 0);
    uint32_t length = message_info_get_msgLength(info);
    uint32_t fault_type = fault_get_faultType(curThread->fault);

    /* Check there's no extra caps, the length is ok and
     * there's no saved fault. */
    if (unlikely(fastpath_mi_check(msgInfo) ||
                 fault_type != fault_null_fault)) {
        slowpath(SysCall);
    }
    /* Lookup the cap */
    cap_t ep_cap = lookup_fp(
        TCB_PTR_CTE_PTR(ksCurThread, tcbCTable)->cap, cptr);
    /* Check it's an endpoint */
    if (unlikely(cap_get_capType(ep_cap) != cap_endpoint_cap ||
                 !cap_endpoint_cap_get_capCanSend(ep_cap))) {
        slowpath(SysCall);
```

```
f001003c <fastpath_call>:
f001003c:   e59f21f4    ldr r2, [pc, #500]  ; f0010238 <fastpa
f0010040:   e1a03b81    lsl r3, r1, #23
f0010044:   e3530402    cmp r3, #33554432   ; 0x2000000
f0010048:   e592c000    ldr ip, [r2]
f001004c:   e92d4080    push    {r7, lr}
f0010050:   e59c3054    ldr r3, [ip, #84]   ; 0x54
f0010054:   8a000075    bhi f0010230 <fastpath_call+0x1f4>
f0010058:   e2133007    ands    r3, r3, #7
f001005c:   1a000073    bne f0010230 <fastpath_call+0x1f4>
f0010060:   e51c4100    ldr r4, [ip, #-256] ; 0xffffff00
f0010064:   e51ce0fc    ldr lr, [ip, #-252] ; 0xffffff04
f0010068:   e204500f    and r5, r4, #15
f001006c:   e3550005    cmp r5, #5
f0010070:   1a00006e    bne f0010230 <fastpath_call+0x1f4>
f0010074:   e20e653e    and r6, lr, #260046848  ; 0xf800000
f0010078:   e1a07310    lsl r7, r0, r3
f001007c:   e1b05ba6    lsrs    r5, r6, #23
f0010080:   0a000004    beq f0010098 <fastpath_call+0x5c>
f0010084:   e2658020    rsb r8, r5, #32
```

For each instruction, ask:

- Why is it there? (what C code generated it?)
- Is it needed? (either superfluous or redundant?)
- Is it causing any pipeline stalls?
- Can the same effect be achieved faster?
- What prevents the compiler from doing so?

Simple examples

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- Unnecessary sign-extension, zero-extension
  - Caused by using `char`, `short` and `signed` types unnecessarily

- Unnecessary bit-masking

- Unnecessary branches
  - Use compiler branch hints to optimise code placement

- Stack spilling
  - Re-write complex expressions
    (help with common subexpression elimination)

- Function calls (e.g. for machine-specific assembly)

More examples: avoiding pipeline stalls

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```
...

/* Check endpoint is not in send state. */
endpoint = *endpointPtr;
if ((endpoint & 0x3) == 0x1) goto slowpath;

/* Check that the caller cap is valid. */
callerCap = *callerCapPtr;
if (callerCap == 0) goto slowpath;

...
```

```
ldr r0, [r4]
and r3, r0, #3
cmp r3, #1
beq slowpath

ldr r3, [ip, #-208]
cmp r3, #0
beq slowpath
```

More examples: avoiding pipeline stalls

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stall x 2

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More examples – avoiding pipeline stalls

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stall x 1

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Was it worth it?

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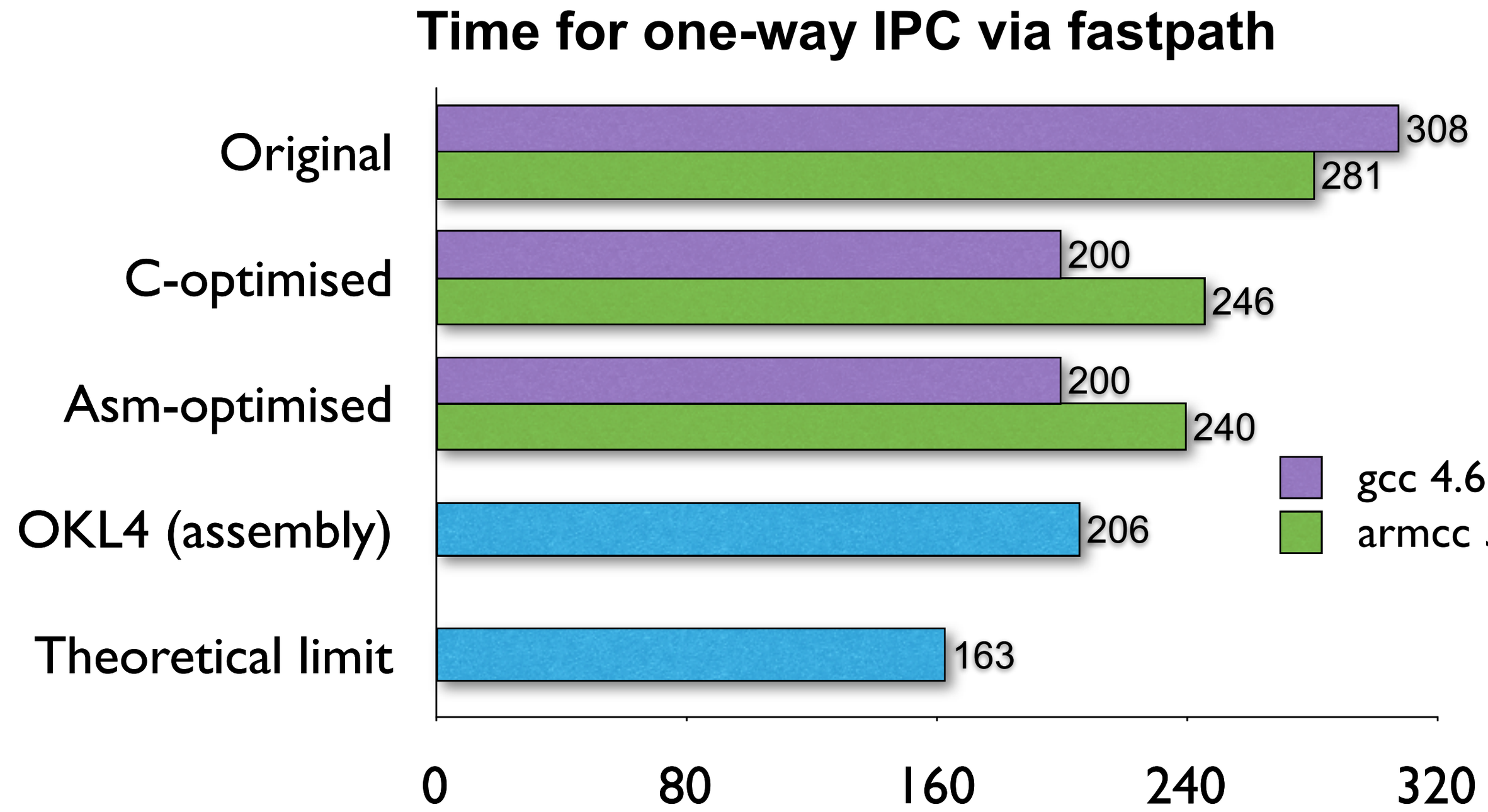

Was it worth it?

- Optimisation effort comparable, if not easier
- Performance is compiler dependent
  - Optimisations can be used by all compilers
- Correctness is obscured
  - Still better than assembly
- Source is less maintainable?
  - comments are good!

Some limitations apply*

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* Our claims hold for:

- RISC instruction sets
- Single-issue pipeline
- Register-rich architecture
- Heavily control-oriented code

Room for more optimisation:

- repurpose sacred registers
- discarding stack completely

Lessons learnt

- Modern compilers are awesome!
- **Verification and performance are not necessarily at odds**
- Applying assembly optimisation techniques to C sources can achieve near-optimal results*

bernard.blackham@nicta.com.au