GNU Jitter
a low-level introduction

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GNU Project

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About this talk

I have a difficult task today. I want to:

- awe you and get you curious
- without enough time to show you details
- I will link references containing more information (For example: [6])

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Interpreters are important:

- programming languages;
- shells;
- regular expressions;
- spreadsheets;
- application scripting and extensions...
- easy, fun to write and play with
- slow

We need compilation

- difficult
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- Formal languages are the best way of interacting with machines [5]
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- GNU epsilon is my attempt
  - a long-term project, rewritten several times

History

GNU epsilon is meant to be efficient, but:

- very "dynamic" in certain execution phases
- written in itself, bootstrapped — Too slow

In 2016 I wrote a canonical threaded-code *language virtual machine.*

- speedup 4-6x — Too little

So I made a separate repository to experiment with language Virtual Machines.

- tried techniques from scientific papers (many by Anton Ertl and the other GForth people [GForth is a very nice GNU package])

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The way out of the interpreters vs compilers dilemma: Language Virtual Machine

Jitter is a *generator* of language virtual machine

- a C code generator (like Bison) working from a human-written specification

Describe programs as composition of (high-level) operations:
- VM "instructions" defined in C by a human
  - easy, flexible
- simple compiler
  - fun!

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Runtime data

VM code "feels" assembly-like, with abstract data:

- (an unlimited number of) registers
- stack(s)

An example program written in an extension language (register VM code)

Example from [6]

The program to run...

```
var a = 1333333333,
    b = 1;

while a <> b do
  if a < b then
    b := b - a;
  else
    a := a - b;
  end;
end;

print a;
```

...Translated into a register-VM routine

```
        mov     1333333333, %r0
        mov     1, %r1
        be      %r0, %r1, $L9
$L3:
        bge     %r0, %r1, $L6
        minus   %r1, %r0, %r1
        b       $L7
$L6:
        minus   %r0, %r1, %r0
$L7:
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$L9:
        print   %r0
        exitvm
```

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```
        mov             1333333333, %r0
        mov             1, %r1
        push-stack      %r0
        push-stack      %r1
        different-stack
        bf-stack        $L24
$L6:
        push-stack      %r0
        push-stack      %r1
        less-stack
        bf-stack        $L15
        push-stack      %r1
        push-stack      %r0
        minus-stack
        pop-stack       %r1
        b               $L19
```

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$L15:
        push-stack      %r0
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$L19:
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A VM instruction example

add VM instruction: Jitter specification, human-written

```
instruction add (?R, ?Rn 1, !R)
  code
    JITTER_ARGN2 = JITTER_ARGN0 + JITTER_ARGN1;
  end
end
```

Instantiate into every possible instantiation of register and immediate. One example:

add specialisation r4/n1/r4: Generated C, macroexpanded, simplified

```
add_r4_n1_r4_begin:
  _local_state.r4 = _local_state.r4 + 1;
add_r4_n1_r4_end:
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add specialisation r4/n1/r4, compiled

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add_r4_n1_r4_begin:
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What Jitter does

In its most efficient mode [1; 4] Jitter

- generates a huge C function containing all of the VM instructions specialisations

and then at runtime, the VM

- copies compiled code for each VM instruction into executable memory, with `mmap`...
- ...the concatenation of the copies is a correct executable routine
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Doing this correctly is complicated

Generated C code very portable, but complicated [1]

- If compiled by GCC it is very fast, thanks to non-portable GNU extensions and (dangerous) tricks [4] ["The fun of playing with fire"]
    - The dangerous tricks are hidden in the generated code: human-written specification is clean
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Overflow arithmetic

add VM instruction: Jitter specification

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instruction addo (?R, ?Rn 1 -1, !R, ?f)
  code
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[Demo]

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Just like Gnulib, trivial to build for users:

- A copy of the Jitter sources distributed as part of the sources of the project using it
  - A sub-directory with its own `configure`, `Makefile.in`...
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Thanks!

Bibliography

[1] Saiu, L. (2017). The art of the language VM *or* Machine-generating virtual machine code *or* Almost zero overhead with almost zero assembly *or* My virtual machine is faster than yours. GNU Hackers' Meeting 2017, Knüllwald-Niederbeisheim, Germany, August 2017. The first public presentation about Jitter, still useful as an introduction. Slides and video recording available from `https://ageinghacker.net/talks/`.

[2] Saiu, L. (2019). Sub-packages, dependencies and information flow. GNU Hackers' Meeting 2019, Madrid, Spain, August 2019. Slides available from `https://ageinghacker.net/talks/`.

[3] Saiu, L. (2021). Informal Jitter talk. Informal live presentation, March 2021. A friendly talk including a live demo, mostly improvised and not particularly well prepared, with friends from the GNU poke project. Video recording available from `https://archive.org/details/jitter-presentation--2021-03-25`.

Bibliography II

[4] Saiu, L. (2022a). GNU Jitter and the illusion of simplicity *or* Copying, patching and combining compiler-generated code in executable memory *or* The Anarchist's guide to GCC *or* The fun of playing with fire. Binary T00ls Summit, online event, 2022. A technical talk about code generation and how it interacts with GCC optimisations. Slides available from `http://ageinghacker.net/talks`, video recording available at `https://binary-tools.net/summit.html`.

[5] Saiu, L. (2022b). In defence of language as an interface — a statement of the obvious. GNU Hackers' Meeting 2022, İzmir, Turkey. Slides available at `https://ageinghacker.net/talks/language-slides--saiu--ghm-2022--2022-10-01.pdf`; Video recording available at `https://audio-video.gnu.org/video/ghm2022/2022-10--language--saiu--ghm.webm`.

[6] Saiu, L. (2023). Jitter (unfinished tutorial). Available at `https://ageinghacker.net/projects/jitter-tutorial/`.