scal.cs.uni-salzburg.at
concurrent data structures

scalloc.cs.uni-salzburg.at
concurrent memory allocator

selfie.cs.uni-salzburg.at

Selfie: What is the Difference between Emulation and Virtualization?

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Eidgenössisch-Technische Hochschule Zürich, March 2017

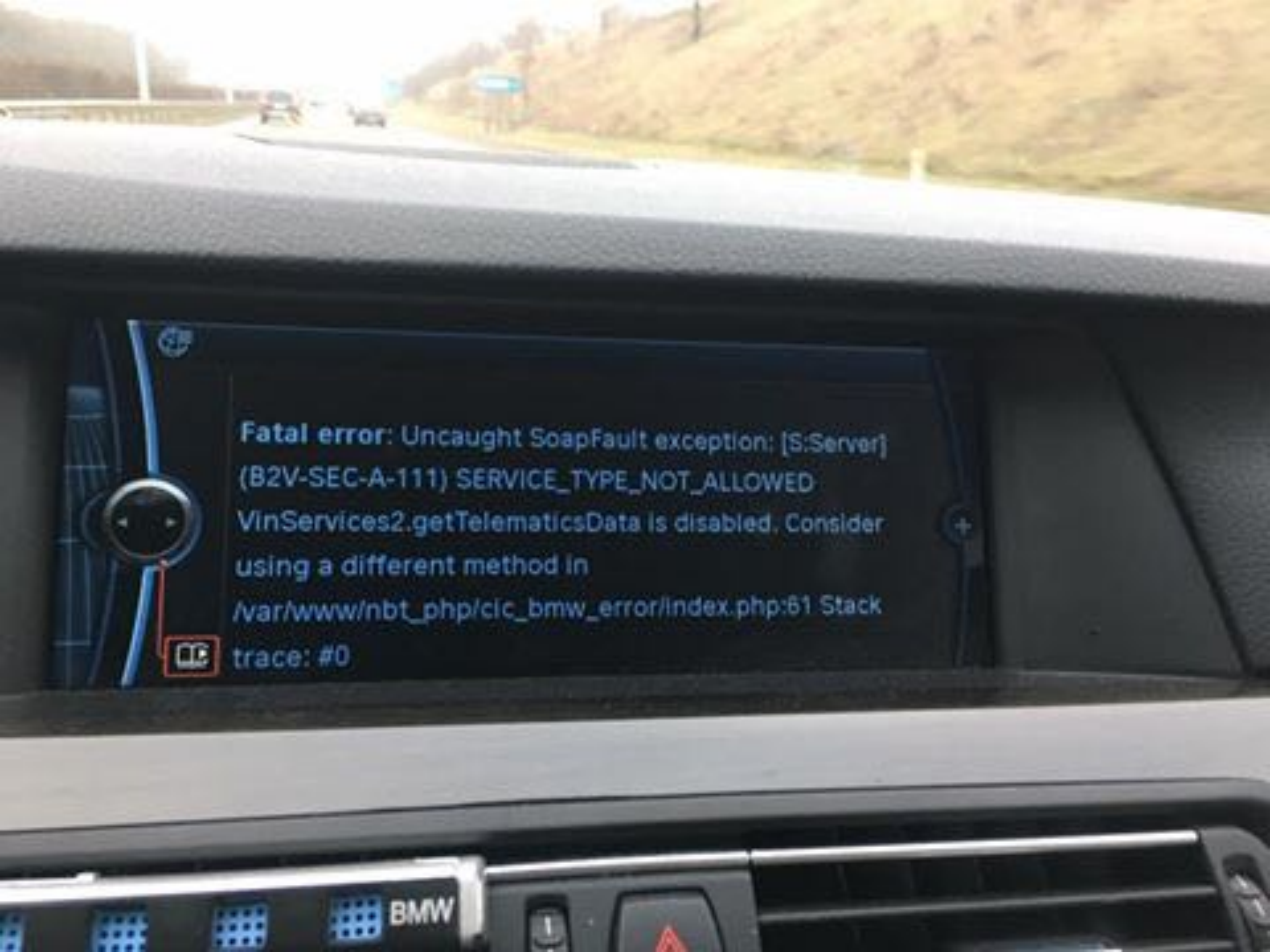
Joint Work

- Martin Aigner, teaching assistant
- Sebastian Arming, teaching assistant
- Christian Barthel, bachelor thesis
  RISC-V port, presented @ Google PhD Summit
- Michael Lippautz, original emulator design
- Simone Oblasser, bachelor thesis
  RISC-V port, presented @ Google PhD Summit

Inspiration

- Niklaus Wirth: Compiler Construction
- Jochen Liedtke: Microkernels

Computer Science for Everyone



```
Fatal error: Uncaught SoapFault exception: [S:Server]
(B2V-SEC-A-111) SERVICE_TYPE_NOT_ALLOWED
VinServices2.getTelematicsData is disabled. Consider
using a different method in
/var/www/nbt_php/cic_bmw_error/index.php:61 Stack
trace: #0
```

nsf.gov/csforall

code.org

computingatschool.org.uk

programbydesign.org

bootstrapworld.org

k12cs.org

csfieldguide.org.nz

Teaching the absolute basics!

What are the absolute basics?

What is Computer Science?

To Create Meaning with a Machine

Selfie: Teaching Computer Science [selfie.cs.uni-salzburg.at]

- *Selfie* is a self-referential 7k-line C implementation (in a single file) of:

    1. a self-compiling compiler called *starc* that compiles a tiny subset of C called C Star (C*) to a tiny subset of MIPS32 called MIPSter,

    2. a self-executing emulator called *mipster* that executes MIPSter code including itself when compiled with starc,

    3. a self-hosting hypervisor called *hypster* that virtualizes mipster and can host all of selfie including itself, and

    4. a tiny C* library called *libcstar* utilized by all of selfie.

Website

selfie.cs.uni-salzburg.at

Book (Draft)

leanpub.com/selfie

Code

github.com/cksystemsteaching/selfie

Discussion of Selfie recently reached 3rd place on Hacker News

news.ycombinator.com

5 statements:
assignment
while
if
return
procedure()

```
int atoi(int *s) {
        int i;
        int n;
        int c;

        i = 0;
        n = 0;
        c = *(s+i);

        while (c != 0) {
                n = n * 10 + c - '0';
                if (n < 0)
                        return -1;

                i = i + 1;
                c = *(s+i);
        }

        return n;
}
```

no data structures,
just `int` and `int*`
and dereferencing:
the * operator

character literals
string literals

integer arithmetics
pointer arithmetics

no bitwise operators
no Boolean operators

library: `exit`, `malloc`, `open`, `read`, `write`

Selfie and Twelve Basic Principles

Library

Compiler

Emulator

Hypervisor

`selfie.c`

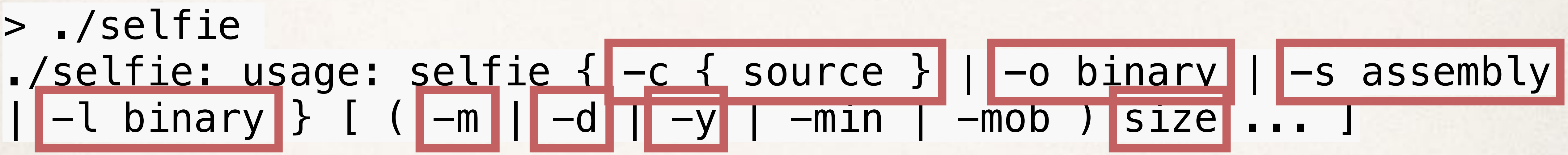
1. Building Selfie
2. Encoding C* Literals
3. Program/Machine State
4. C*/Command Line Scanners
5. C* Parser and Procedures
6. Symbol Table and the Heap
7. MIPSter Code Generator
8. Memory Management
9. Composite Data Types
10. MIPSter Boot Loader
11. MIPSter Emulator
12. MIPSter Hypervisor

1. Semantics
2. Encoding
3. State
4. Regularity
5. Stack
6. Name
7. Time
8. Memory
9. Type
10. Bootstrapping
11. Interpretation
12. Virtualization

```
> make
cc -w -m32 -D'main(a,b)=main(a,char**argv)' selfie.c -o selfie
```

bootstrapping `selfie.c` *into x86* `selfie` *executable*
using standard C compiler

(now also available for RISC-V machines)



```
> ./selfie
./selfie: usage: selfie { -c { source } | -o binary | -s assembly
| -l binary } [ ( -m | -d | -y | -min | -mob ) size ... ]
```

selfie usage

```
> ./selfie -c selfie.c

./selfie: this is selfie's starc compiling selfie.c

./selfie: 176408 characters read in 7083 lines and 969 comments
./selfie: with 97779(55.55%) characters in 28914 actual symbols
./selfie: 261 global variables, 289 procedures, 450 string literals
./selfie: 1958 calls, 723 assignments, 57 while, 572 if, 243 return
./selfie: 121660 bytes generated with 28779 instructions and 6544
bytes of data
```

compiling `selfie.c` *with x86* `selfie` *executable*

*(**takes seconds**)*

```
> ./selfie -c selfie.c -m 2 -c selfie.c

./selfie: this is selfie's starc compiling selfie.c

./selfie: this is selfie's mipster executing selfie.c with 2MB of
physical memory

selfie.c: this is selfie's starc compiling selfie.c

selfie.c: exiting with exit code 0 and 1.05MB of mallocated memory

./selfie: this is selfie's mipster terminating selfie.c with exit code
0 and 1.16MB of mapped memory
```

compiling `selfie.c` *with x86* `selfie` *executable into a MIPSter executable*

and

then running that MIPSter executable to compile `selfie.c` *again*

*(**takes ~6 minutes**)*

```
> ./selfie -c selfie.c -o selfie1.m -m 2 -c selfie.c -o selfie2.m

./selfie: this is selfie's starc compiling selfie.c
./selfie: 121660 bytes with 28779 instructions and 6544 bytes of data
written into selfie1.m

./selfie: this is selfie's mipster executing selfie1.m with 2MB of
physical memory

selfie1.m: this is selfie's starc compiling selfie.c
selfie1.m: 121660 bytes with 28779 instructions and 6544 bytes of data
written into selfie2.m

selfie1.m: exiting with exit code 0 and 1.05MB of mallocated memory

./selfie: this is selfie's mipster terminating selfie1.m with exit
code 0 and 1.16MB of mapped memory
```

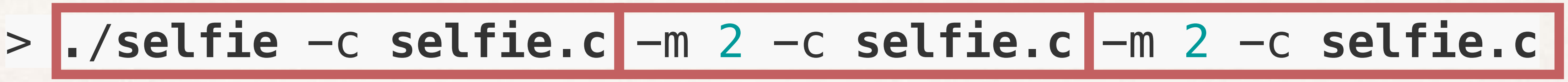
compiling `selfie.c` *into a MIPSter executable* `selfie1.m`

and

then running `selfie1.m` *to compile* `selfie.c`

into another MIPSter executable `selfie2.m`

*(**takes ~6 minutes**)*



```
> ./selfie -c selfie.c -m 2 -c selfie.c -m 2 -c selfie.c
```

compiling `selfie.c` *with x86* `selfie` executable

and

then running that executable to compile `selfie.c` *again*

and

then running that executable to compile `selfie.c` *again*

*(**takes ~24 hours**)*

“The OS is an interpreter until people wanted speed.”

–ck

```
> ./selfie -c selfie.c -m 2 -c selfie.c -y 2 -c selfie.c
```

compiling `selfie.c` *with x86* `selfie` *executable*

and

then running that executable to compile `selfie.c` *again*

and

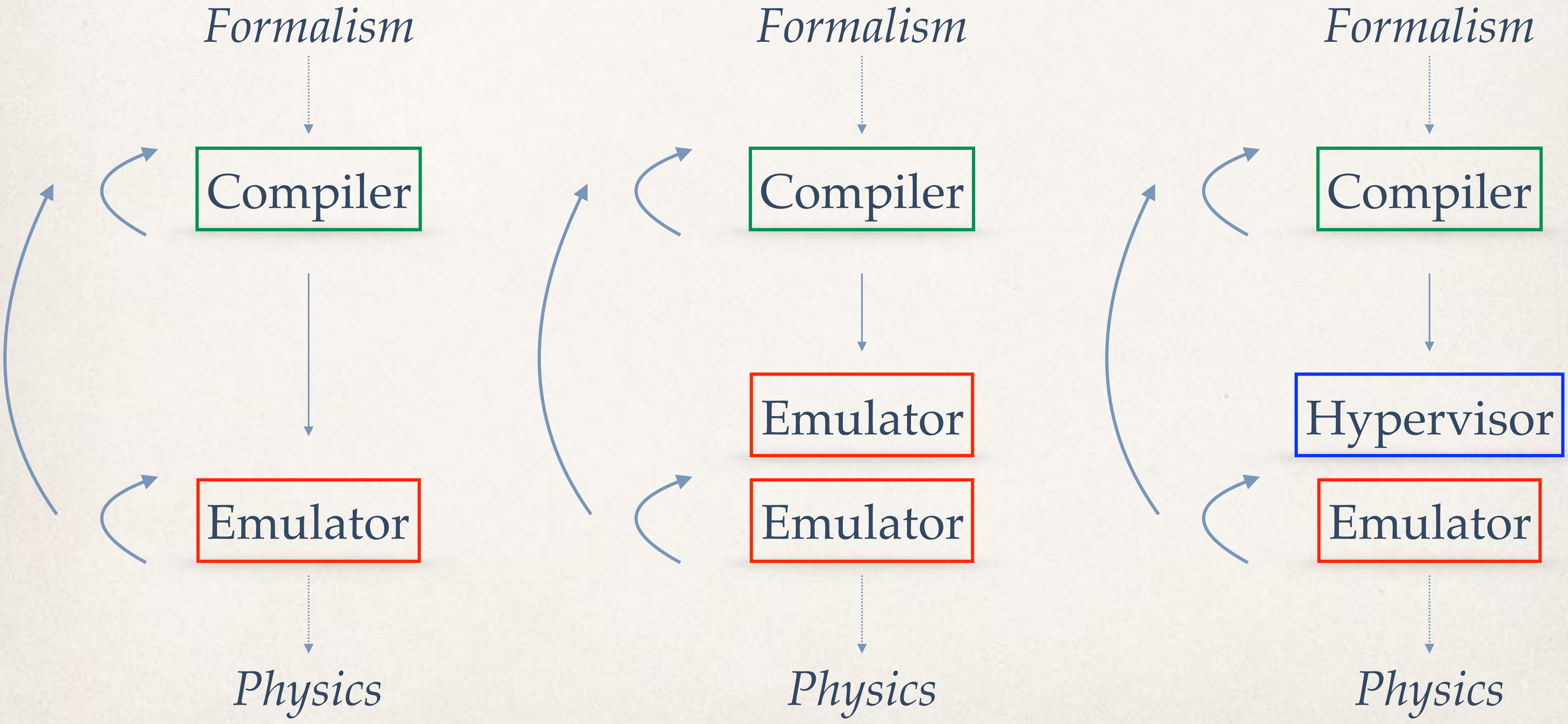
then ***hosting*** *that executable in a virtual machine to compile* `selfie.c` *again*

*(**takes ~12 minutes**)*

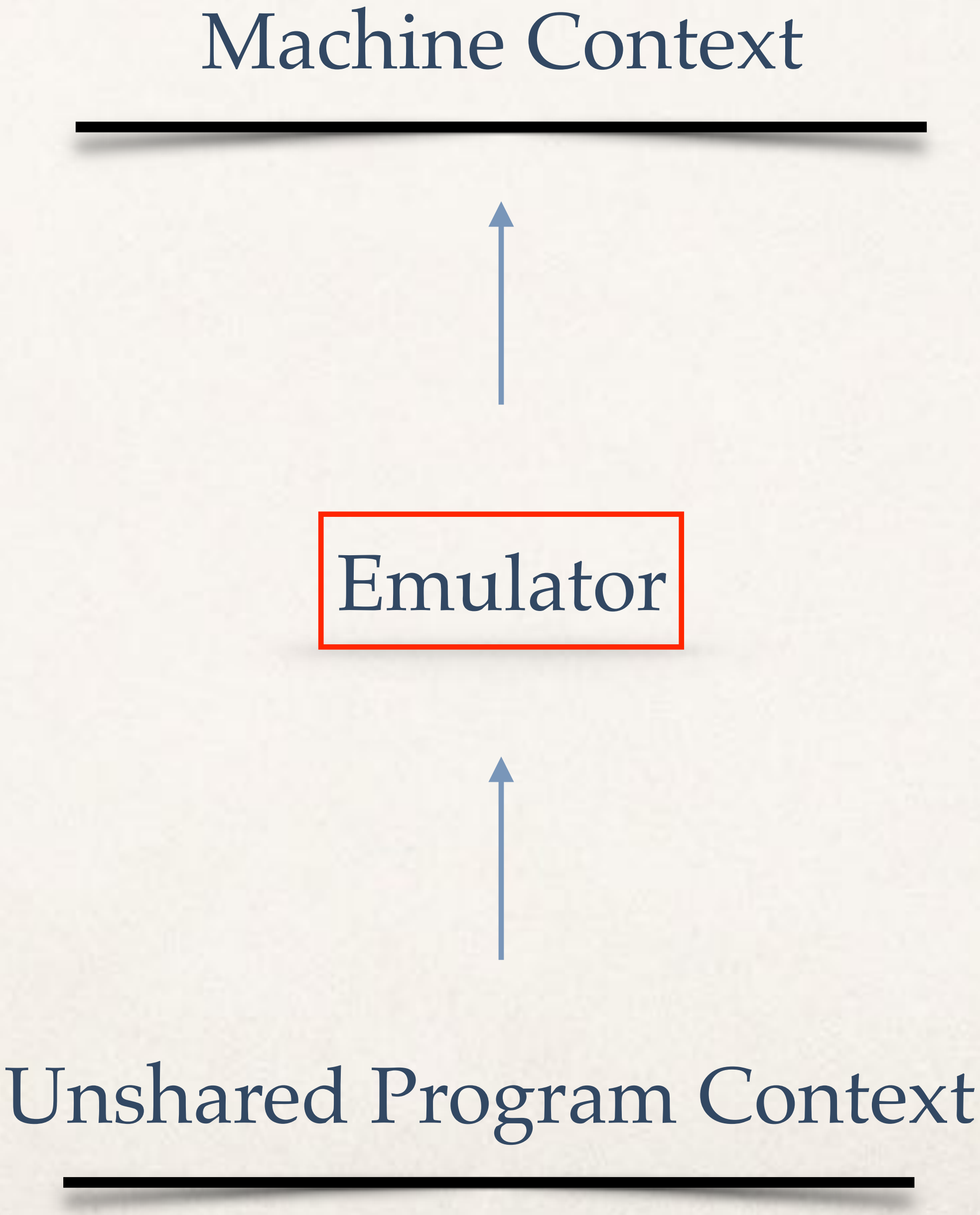
“How do we introduce self-model-checking and maybe even self-verification into Selfie?”

https://github.com/cksystemsteaching/selfie/tree/vipster

Semantics and Performance



Emulation

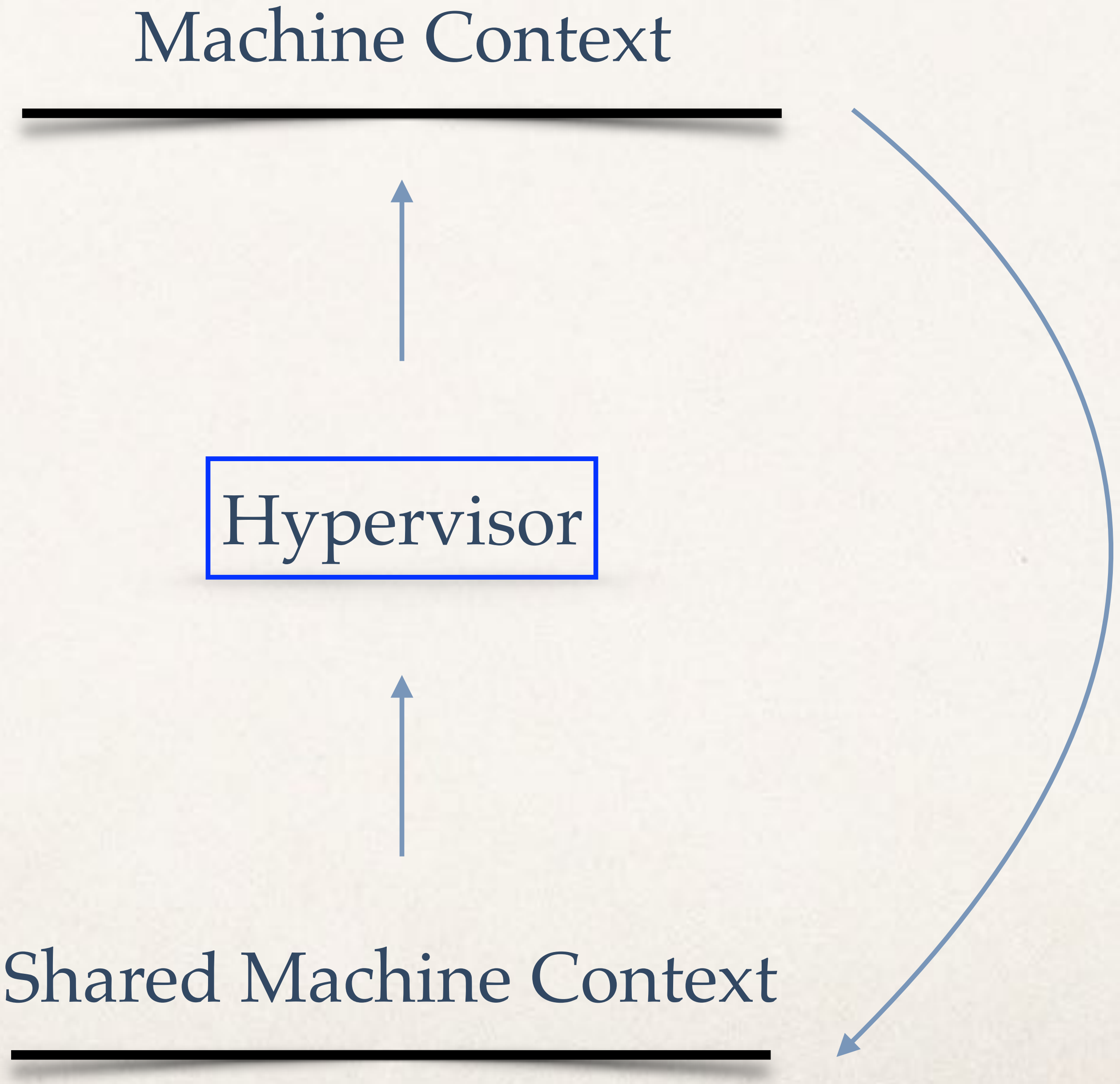


Machine Context

Emulator

Unshared Program Context

Virtualization



Machine Context

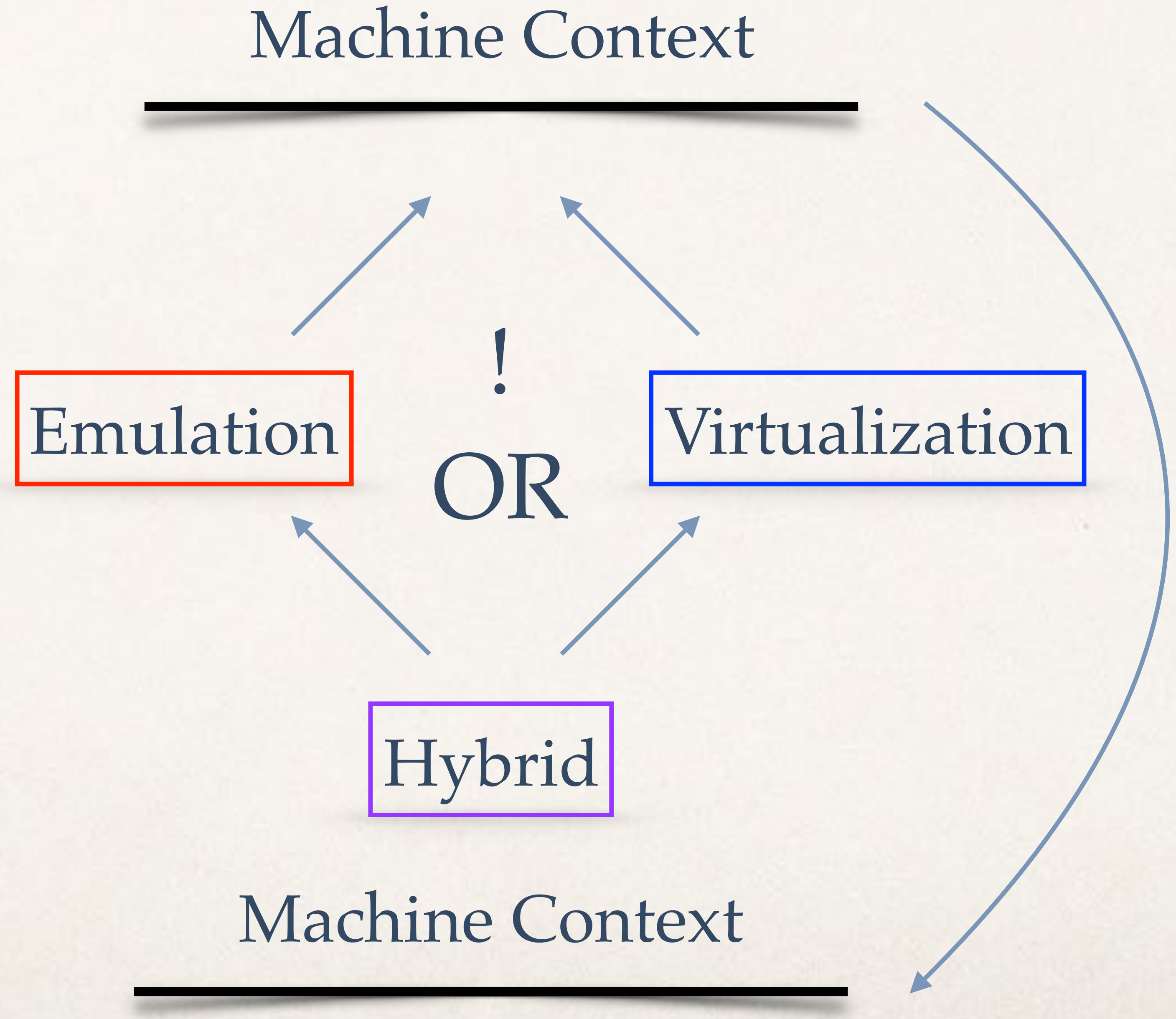
Hypervisor

Shared Machine Context

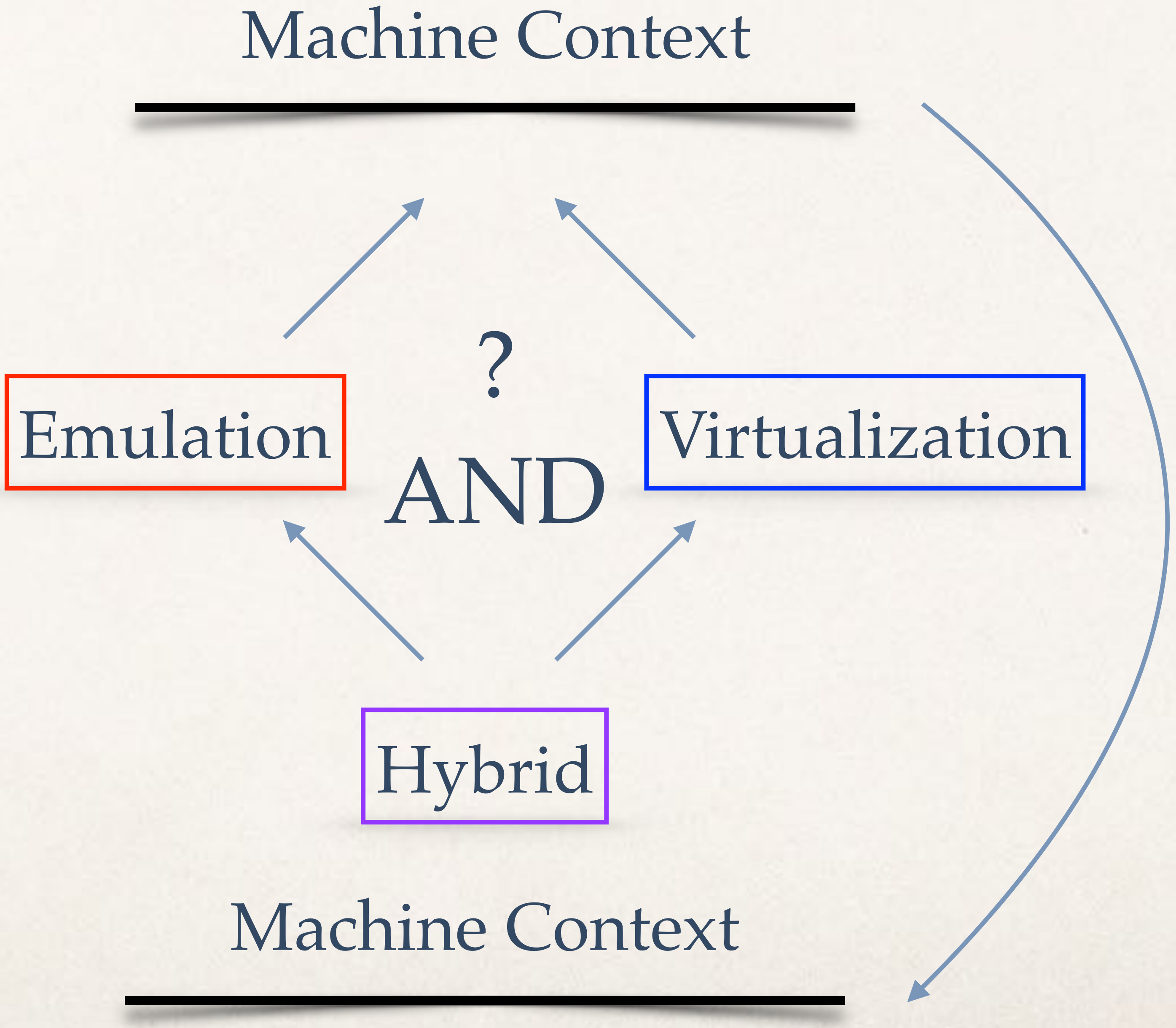
Proof Obligation

$$\frac{\text{Machine Context}}{\boxed{\text{Emulator}}} \overset{?}{=} \frac{\text{Machine Context}}{\boxed{\text{Hypervisor}}}$$

Hybrid of Emulator & Hypervisor



Validation of Functional Equivalence?



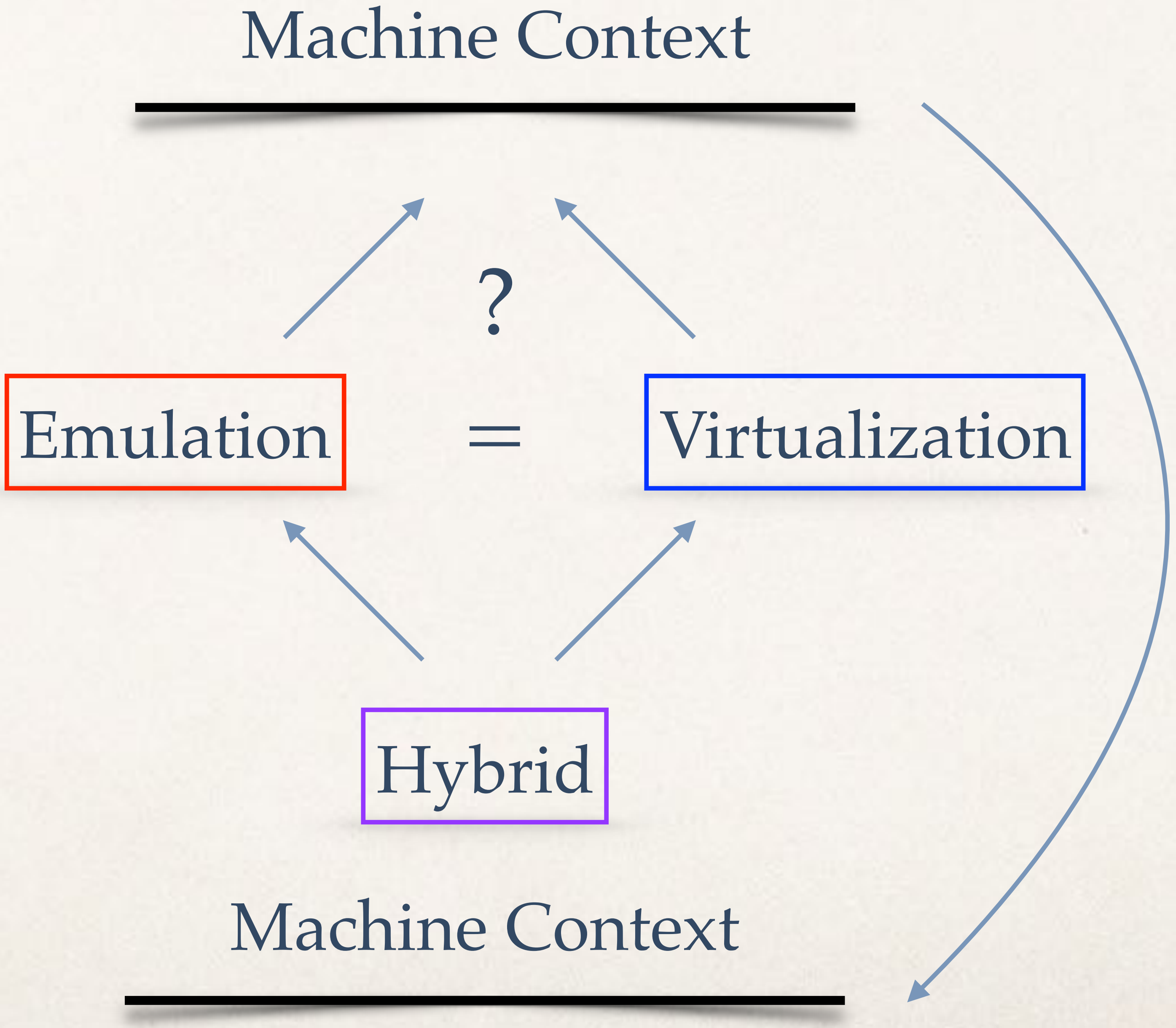
Machine Context

?

AND

Machine Context

Verification of Functional Equivalence?



Questions

- What are the benefits of the hybrid design in Selfie?
- Will these benefits change the design of real kernels, that is, is the hybrid design realistic?
- Can we develop C* into a useful specification language, cf. ACL2?
- Can we prove interesting properties with a, say, ~10k-line system?
- Will this help teaching rigorous systems and software engineering at bachelor level?
- Will this help identifying basic principles that can be taught to everyone?

Thank you!