Selfie and the Basics

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What are the absolute basics of computer science that everyone should know about and understand?

1. Identify a concept that you feel everyone should know about and understand
2. Write a program that exemplifies that concept in different ways
3. List the basics that you need to know about and understand to understand that program

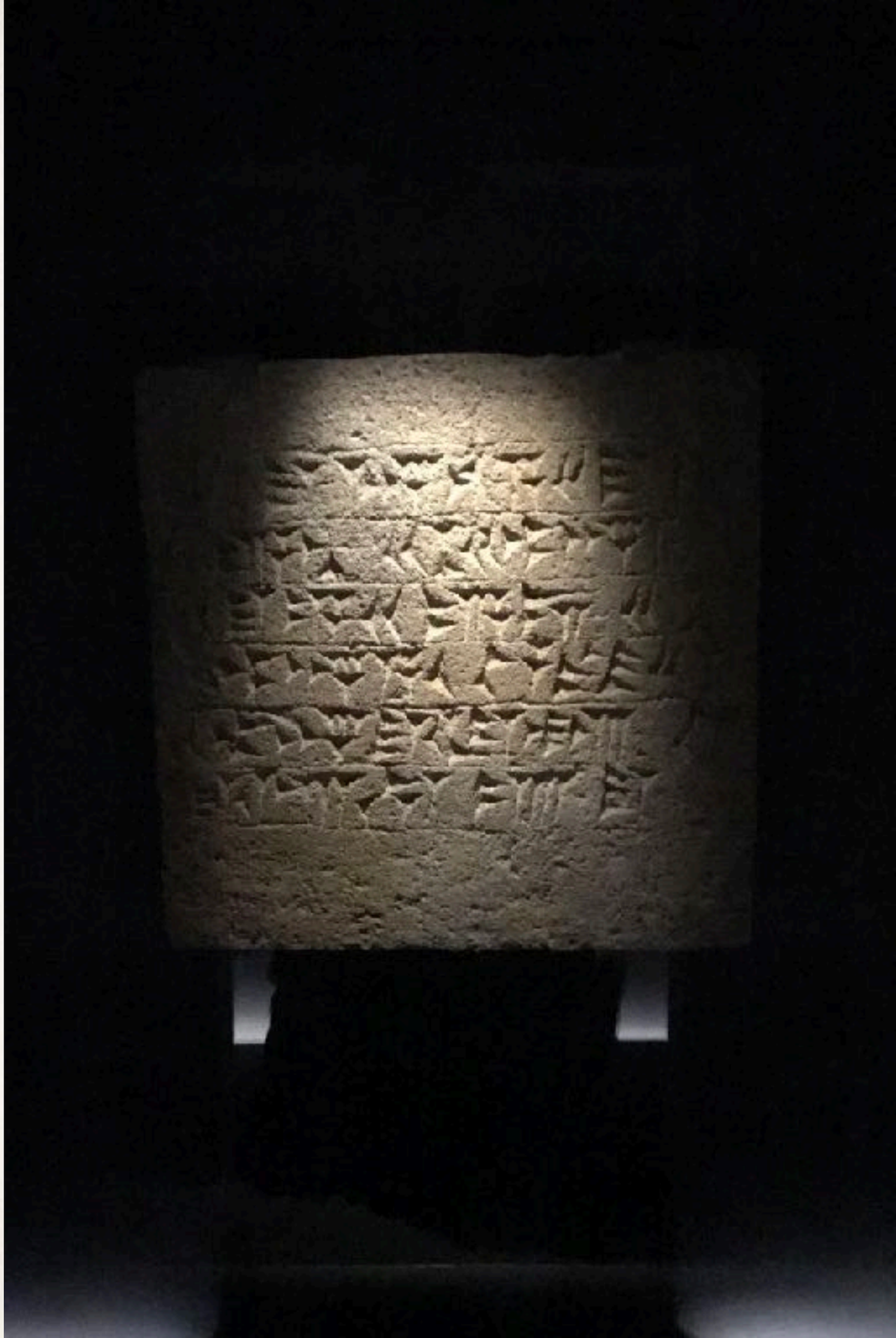
selfie.cs.uni-salzburg.at

...and the Basics:

12 (!) basic principles
essential (!) for understanding
selfie and (?) computer science

What is the meaning of this sentence?

Selfie as in self-referentiality



Do people need to understand self-referentiality?

Programming languages resemble languages but are really just formalisms with (hopefully) precise semantics

Interpretation

Compilation

Teaching the Construction of Semantics of Formalisms

Virtualization

Verification

Joint Work

- Alireza Abyaneh
- Martin Aigner
- Sebastian Arming
- Christian Barthel
- Simon Bauer
- Thomas Hütter
- Alexander Kollert
- Michael Lippautz
- Cornelia Mayer
- Philipp Mayer
- Christian Moesl
- Simone Oblasser
- Clement Poncelet
- Sara Seidl
- Ana Sokolova
- Manuel Widmoser

Inspiration

- Armin Biere: SAT/SMT Solvers
- Donald Knuth: Art
- Jochen Liedtke: Microkernels
- David Patterson: RISC
- Niklaus Wirth: Compilers

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 MIPS64/RISC-V 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,
4. a tiny C* library called ***libcstar*** utilized by all of selfie, and
5. a tiny, experimental SAT solver called ***babysat***.

Also, there is a…

- linker (in-memory only)
- disassembler (w/ source code line numbers)
- debugger (tracks full machine state)
- profiler (#proc-calls, #loop-iterations, #loads, #stores)

Discussion of Selfie recently reached 3rd place on Hacker News

news.ycombinator.com

Website

selfie.cs.uni-salzburg.at

Book (Draft)

leanpub.com/selfie

Code

github.com/cksystemsteaching/selfie

nsf.gov / csforall

code.org

computingatschool.org.uk

programbydesign.org

bootstrapworld.org

k12cs.org

csfieldguide.org.nz

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 types other than `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`

Minimally complex, maximally self-contained system

Programming languages vs systems engineering?

```
> 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

(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`

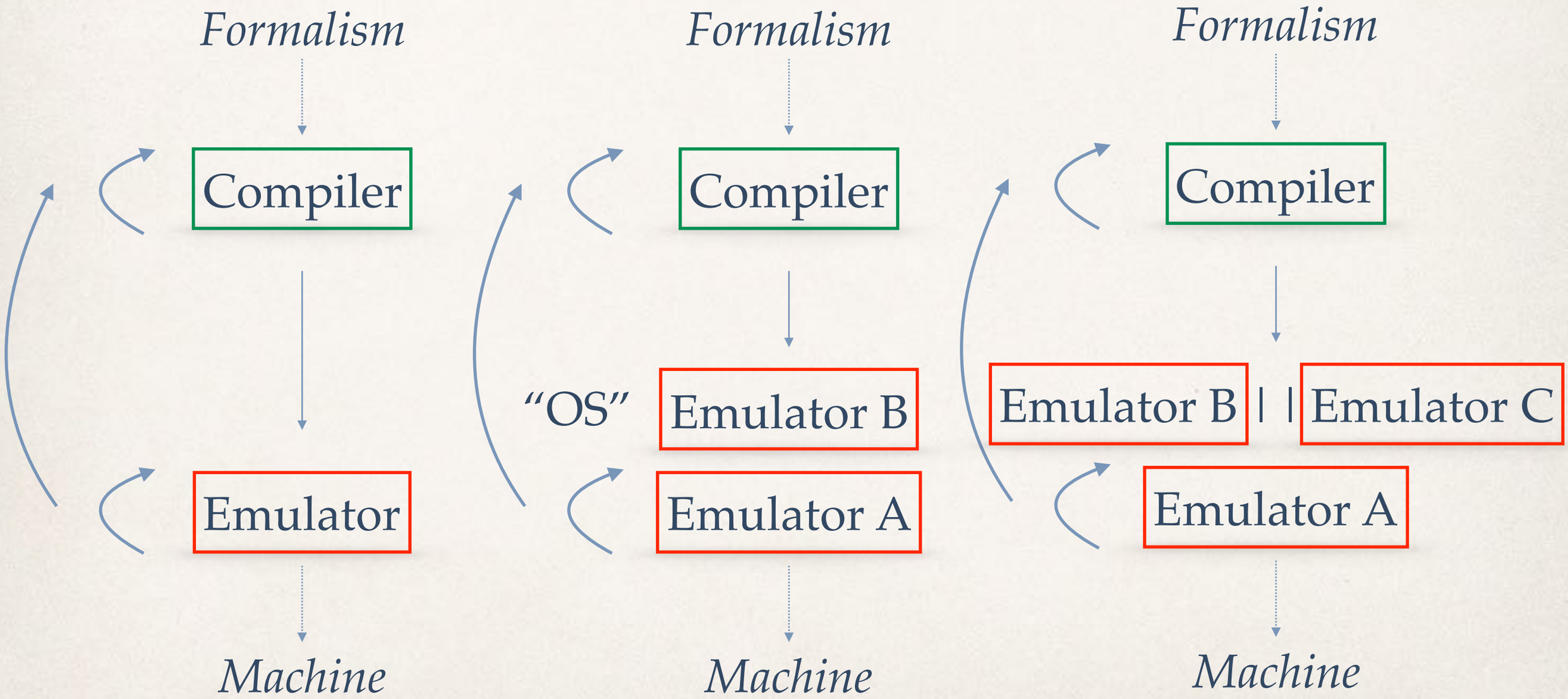
and

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

into another MIPSter executable `selfie2.m`

(takes ~6 minutes)

Implementing an OS Kernel: 1-Week Homework Assignment



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

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

and

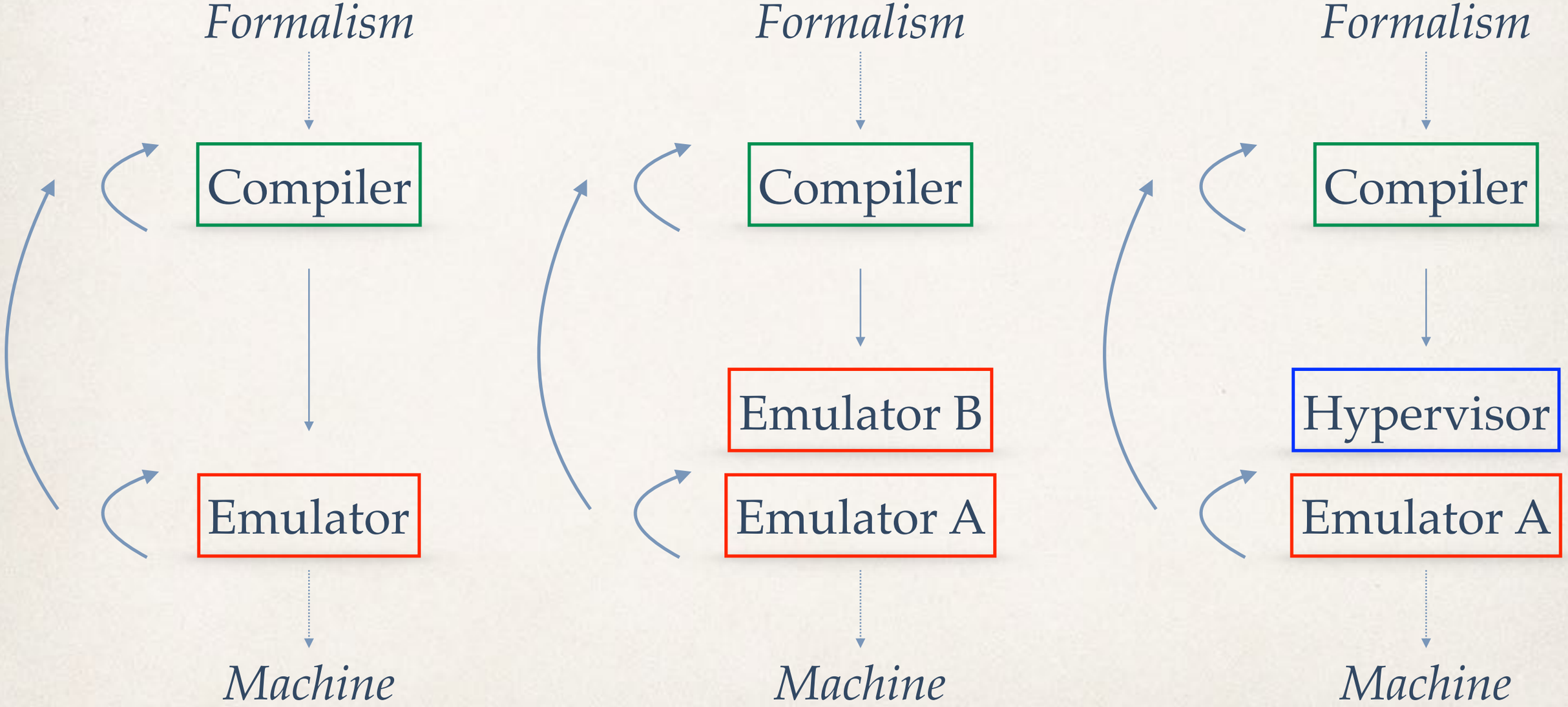
then running that executable to compile `selfie.c` *again*

and

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

(takes ~24 hours)

Emulation versus Virtualization



```
> ./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)

Ongoing Work

Verification

- SAT/SMT Solvers (microsat/boolector)
- Symbolic Execution Engine (KLEE/SAGE)
- Inductive Theorem Prover (ACL2)

-> microsat in C* is as fast as in C (forget structs, arrays, &&, ||, goto)

ISAs

1. Large memory and multicore support
2. x86 support through binary translation
3. ARM support?

babysat this

```
./selfie -sat rivest.cnf
./selfie: this is selfie loading SAT instance rivest.cnf
./selfie: 7 clauses with 4 declared variables loaded from rivest.cnf
p cnf 4 7
2 3 -4 0
1 3 4 0
-1 2 4 0
-1 -2 3 0
-2 -3 4 0
-1 -3 -4 0
1 -2 -4 0
./selfie: rivest.cnf is satisfiable with -1 -2 3 4
```

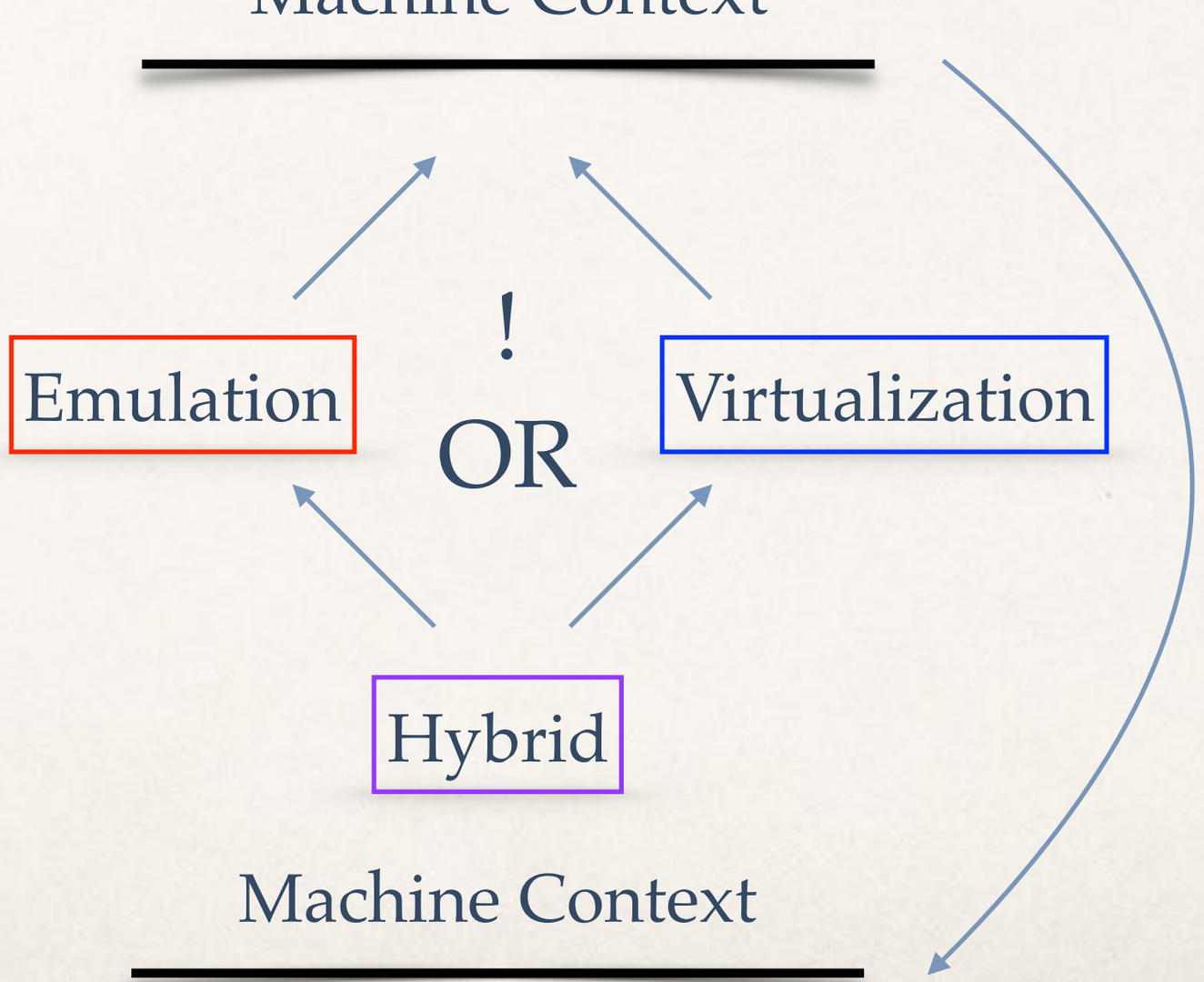
What is the absolute simplest way of proving non-trivial properties of Selfie using Selfie, and what are these properties?

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

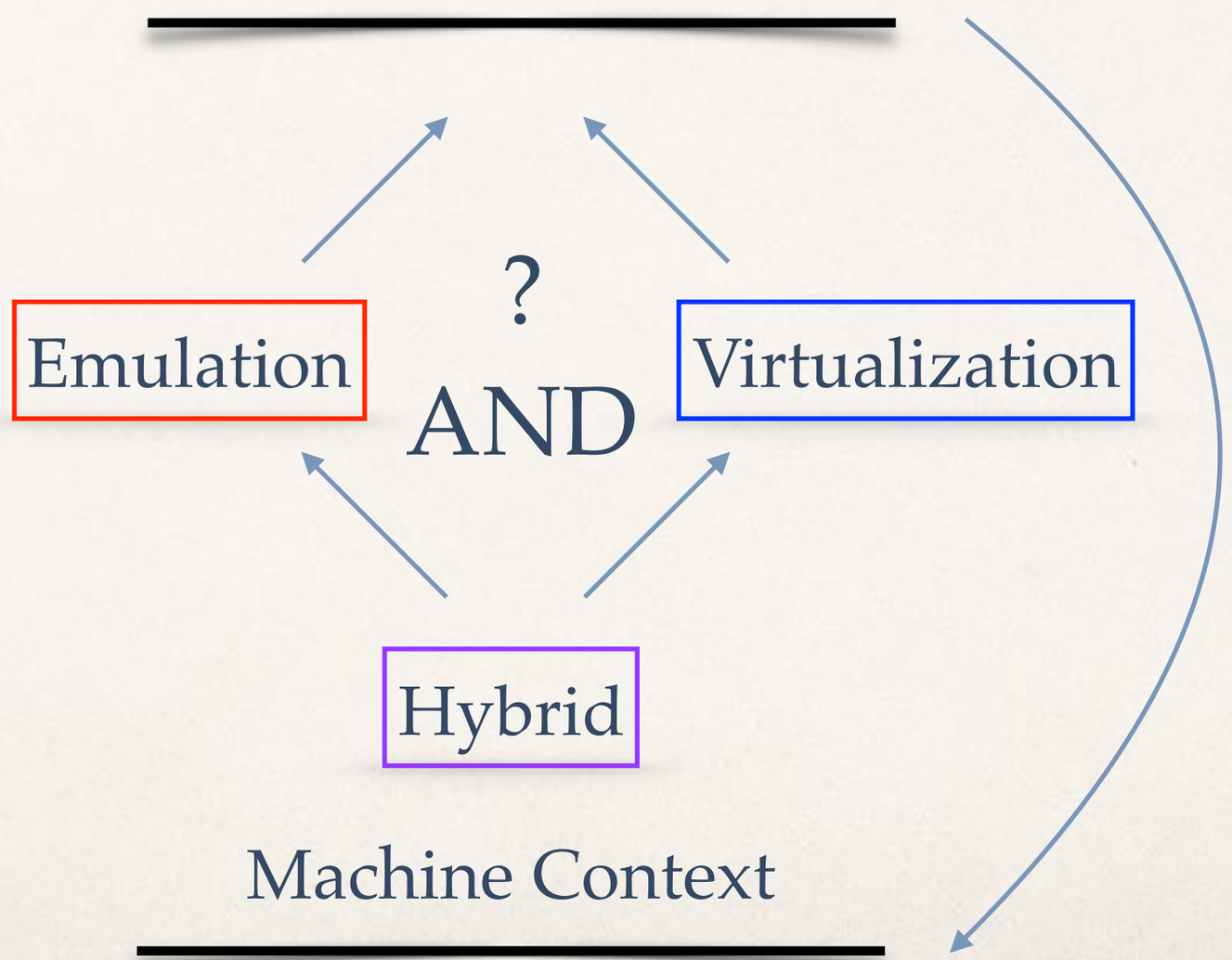
Proof Obligation

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

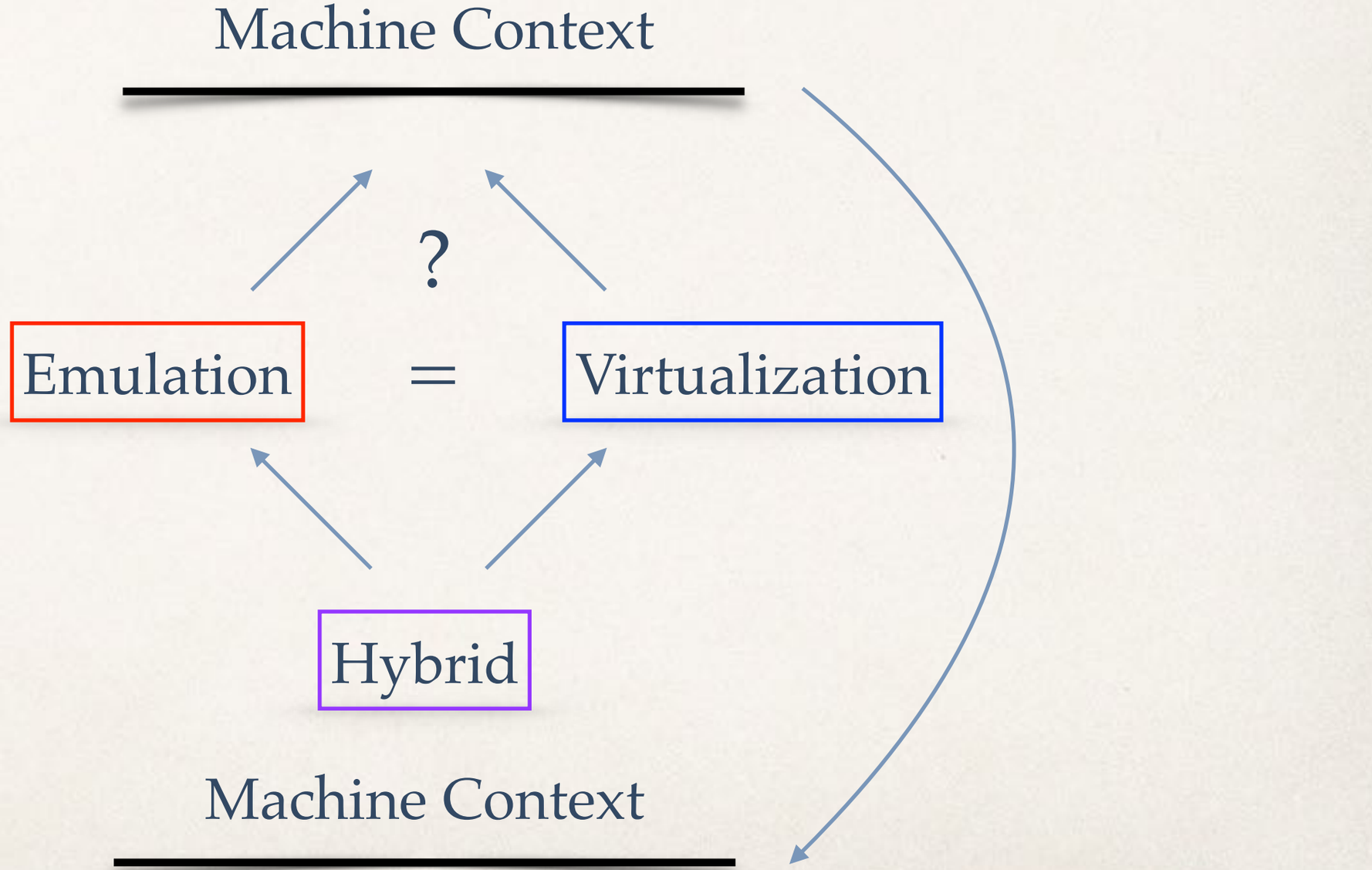
Mixter (T. Hütter, MS Thesis, 2017): Hybrid of Emulator & Hypervisor



Validation of Functional Equivalence?



Verification of Functional Equivalence?



Selfie and the Basics

Library

Compiler

Emulator
Hypervisor
SAT Solver

`selfie.c`

- Building and Using Selfie:
- Handling C* Literals:
- Program/Machine State:
- C*/Command Line Scanners:
- C* Parser and Procedures:
- Symbol Table and the Heap:
- MIPSter Code Generator:
- Address Spaces and Storage:
- (Composite) Data Types:
- MIPSter Boot Loader:
- MIPSter Emulator:
- 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

Thank you!

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