Why systems fail?
- blue screen, leaked pictures, dictators, cancer -
How to stop them?

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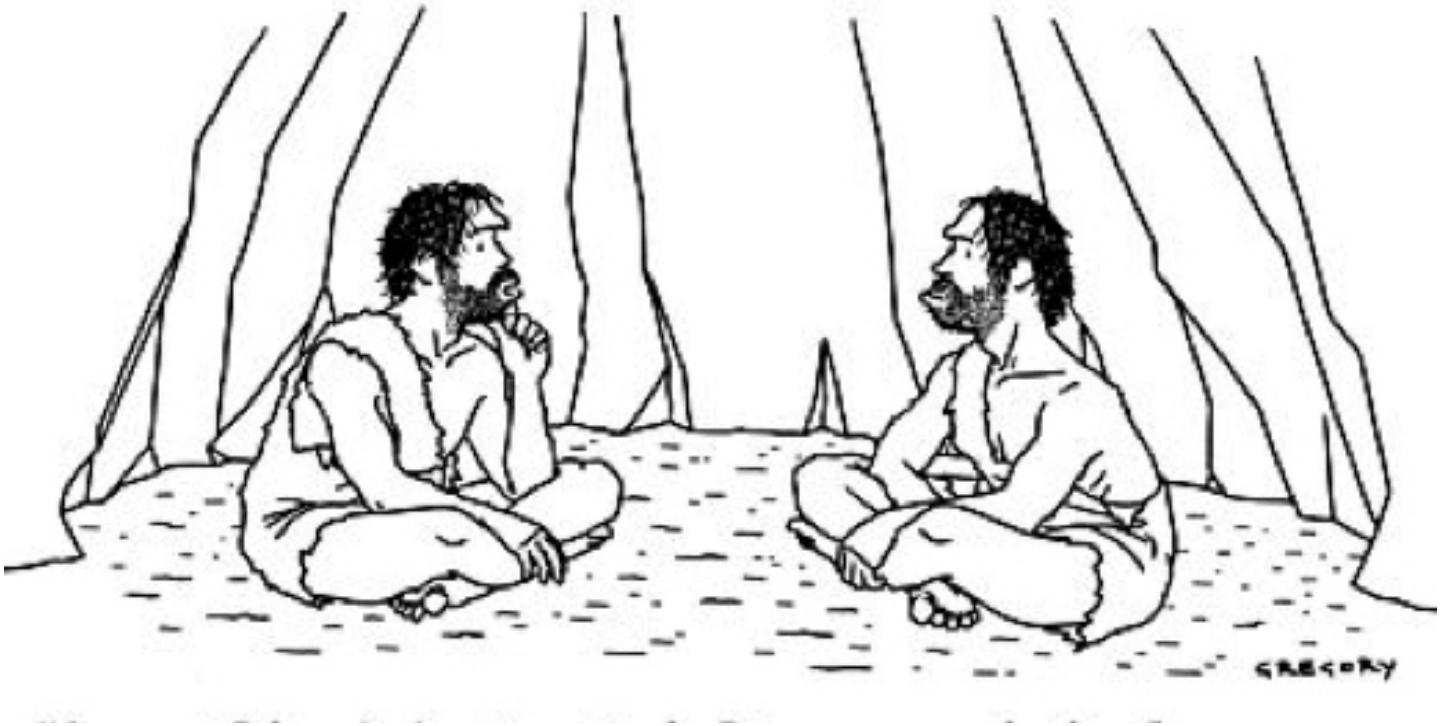
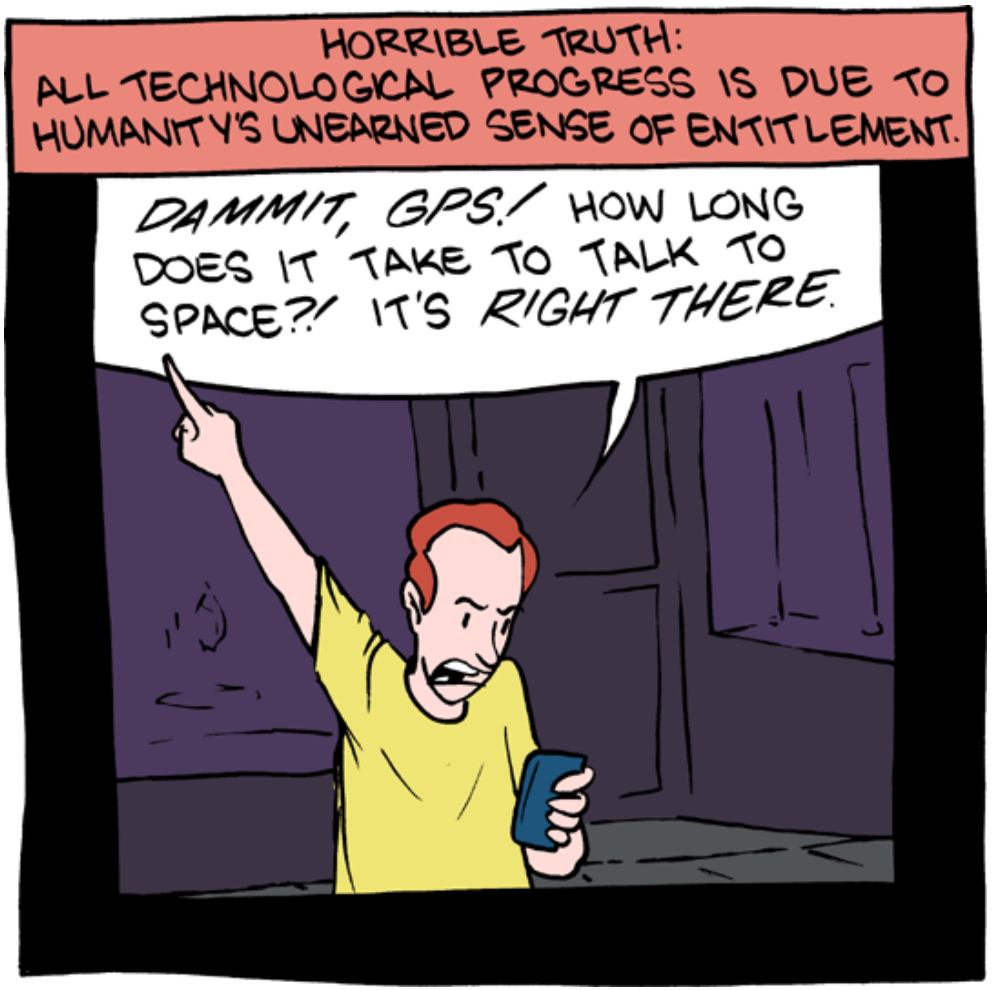
There was a simple life



"Something's not right – our air and water is clean, we get plenty of exercise, everything we eat is organic and free-range, and yet nobody lives past thirty"

And progress happened



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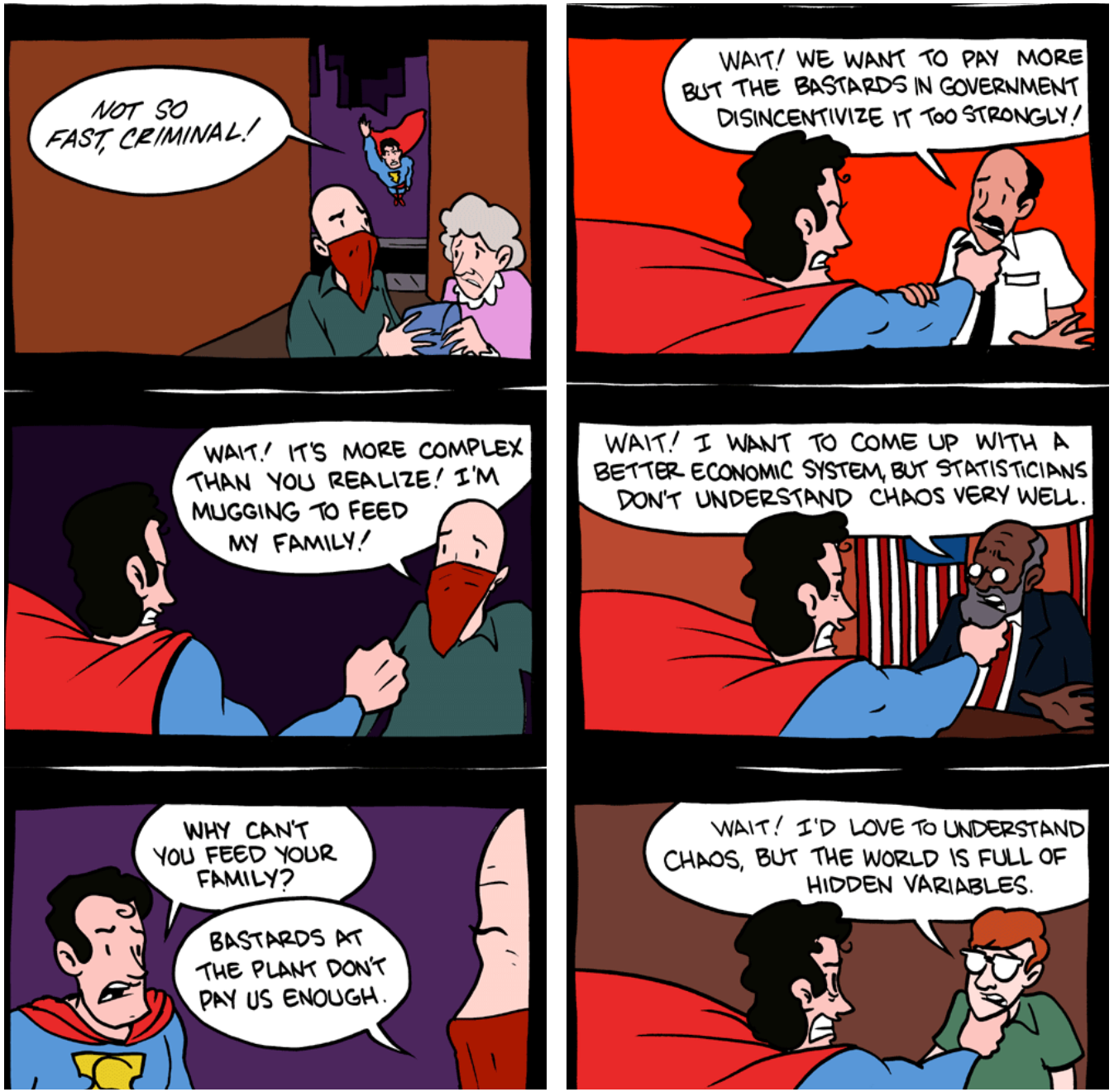

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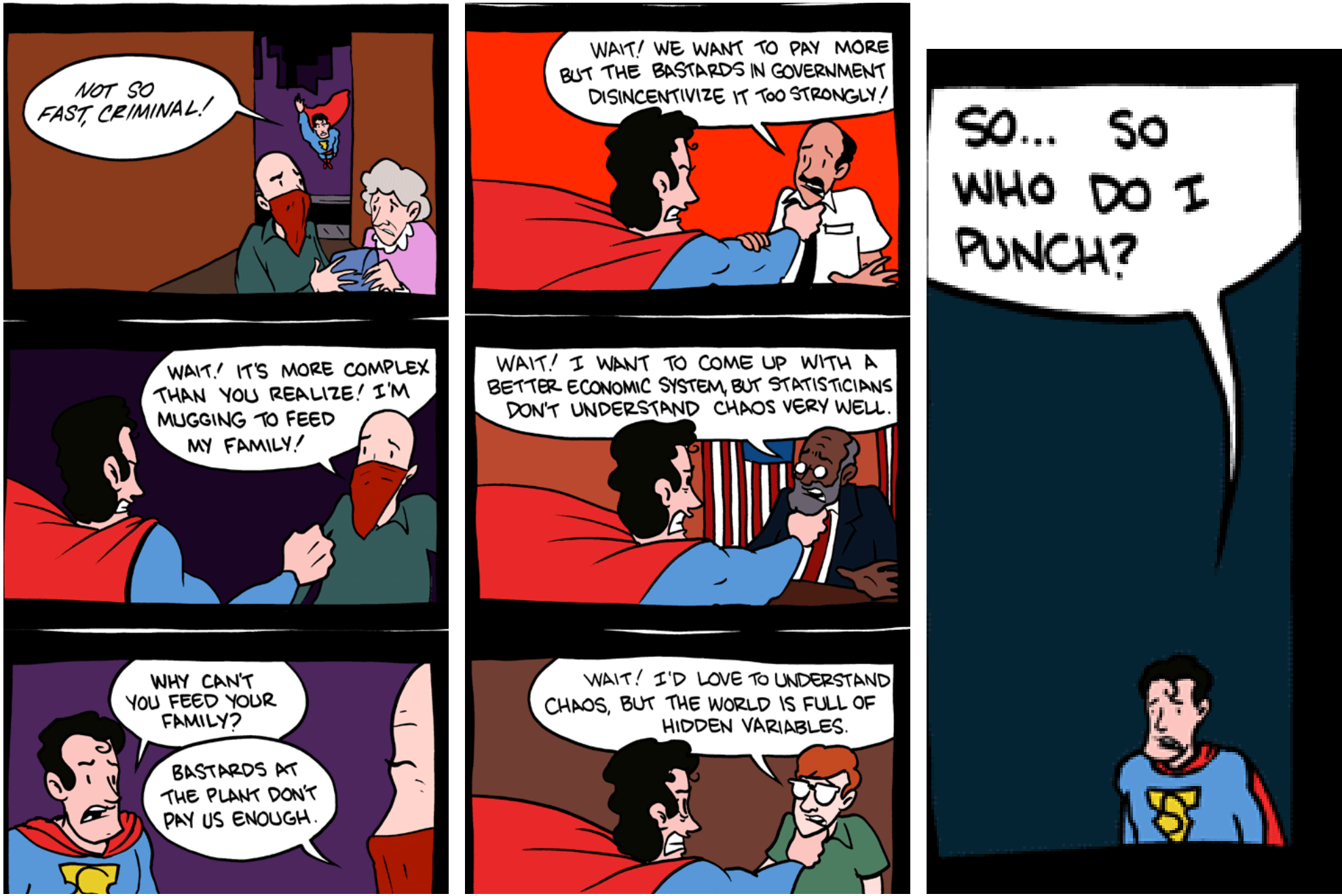

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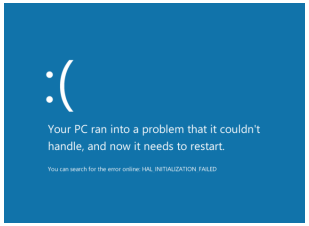

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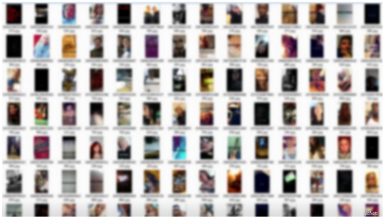
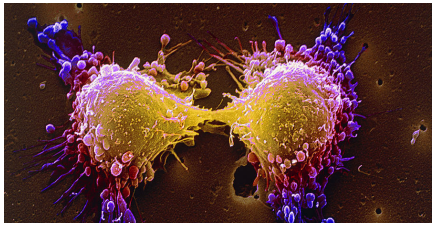


Leaked pictures

Dictators



Cancer

Often our systems show undesired behaviors!!

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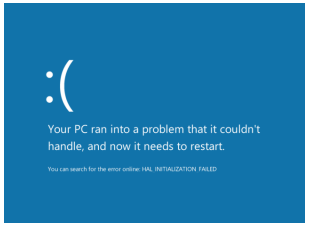

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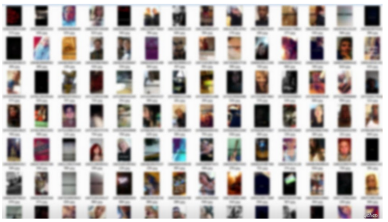

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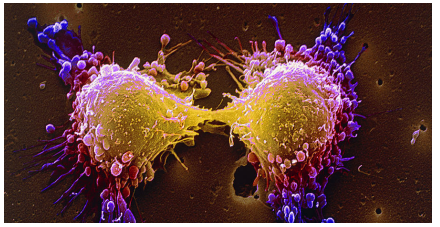

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How can we build bug-free systems?

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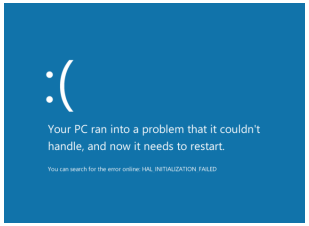

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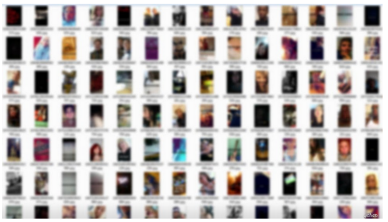

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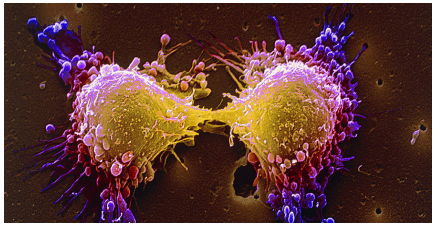

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Let us look at an example (play video).

Example: Ariane 5 failure

From the failure report: "... software exception (in the navigation system) was caused during execution of a data conversion from 64-bit floating point to 16-bit ... (the) number which was converted had a value greater than what could be represented by a 16-bit ..."

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Essentially, a misunderstanding of the nature of the system.

Desired behaviors

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- it does not explode in flight (safety)
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The specifications may not be explicitly available to us.

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Example 1.1

Government

Safety

Liveness

Development tools

Once we have the goals then we need right set of tools to design the system

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For example,

- Programming language or instruments
- Organizational structure
- Skills of people

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	B	C	I	J	K	L	M
2			Real GDP growth				
3			Debt/GDP				
4	Country	Coverage	30 or less	30 to 60	60 to 90	90 or above	30 or less
26			3.7	3.0	3.5	1.7	5.5
27	Minimum		1.6	0.3	1.3	-1.8	0.8
28	Maximum		5.4	4.9	10.2	3.6	13.3
29							
30	US	1946-2009	n.a.	3.4	3.3	-2.0	n.a.
31	UK	1946-2009	n.a.	2.4	2.5	2.4	n.a.
32	Sweden	1946-2009	3.6	2.9	2.7	n.a.	6.3
33	Spain	1946-2009	1.5	3.4	4.2	n.a.	9.9
34	Portugal	1952-2009	4.8	2.5	0.3	n.a.	7.9
35	New Zealand	1948-2009	2.5	2.9	3.9	-7.9	2.6
36	Netherlands	1956-2009	4.1	2.7	1.1	n.a.	6.4
37	Norway	1947-2009	3.4	5.1	n.a.	n.a.	5.4
38	Japan	1946-2009	7.0	4.0	1.0	0.7	7.0
39	Italy	1951-2009	5.4	2.1	1.8	1.0	5.6
40	Ireland	1948-2009	4.4	4.5	4.0	2.4	2.9
41	Greece	1970-2009	4.0	0.3	2.7	2.9	13.3
42	Germany	1946-2009	3.9	0.9	n.a.	n.a.	3.2
43	France	1949-2009	4.9	2.7	3.0	n.a.	5.2
44	Finland	1946-2009	3.8	2.4	5.5	n.a.	7.0
45	Denmark	1950-2009	3.5	1.7	2.4	n.a.	5.6
46	Canada	1951-2009	1.9	3.6	4.1	n.a.	2.2
47	Belgium	1947-2009	n.a.	4.2	3.1	2.6	n.a.
48	Austria	1948-2009	5.2	3.3	-3.8	n.a.	5.7
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50							
51			4.1	2.8	2.8	=AVERAGE(L30:L44)	

Last five rows are skipped!

Example: bad excel (contd.)

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Excel should not be used for any serious work!!

Tools for analysis

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In the state space, the distribution of the errors is unknown.

We are dealing with an ugly beast!

Only continuous math is inappropriate

The classic methods such as differential equations, linear optimizations, simulation, important sampling, etc are the shiny knights that have slayed many problems.

Unfortunately, these methods are insufficient in our setting.

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We need to make unholy alliances. The search is often aided by smart optimizations and machine learning that tells where to search first.

Topic 1.1

Formal Verification 101

“Fronts” of software reliability

Language design

Systematic testing

“Fronts” of software reliability

Language design | Systematic testing | Programming environments | Technical education

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Formal Verification | Automated Synthesis

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"Fronts" of software reliability

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Heterogeneous technologies need to work together for effective reliability

Verification problem

$$\text{Program} \overset{?}{\Rightarrow} \text{Property}$$

- Hardware
- Software

- Safety
- Liveness
- Quantitative
- Probabilistic

Software verification

- Desired property is expresses as a logical formula ψ
- For a given program P, we aim to prove theorem

$$P \Rightarrow \psi$$

(all behaviors of P satisfy ψ)

Abstraction is the key method to prove $P \Rightarrow \psi$

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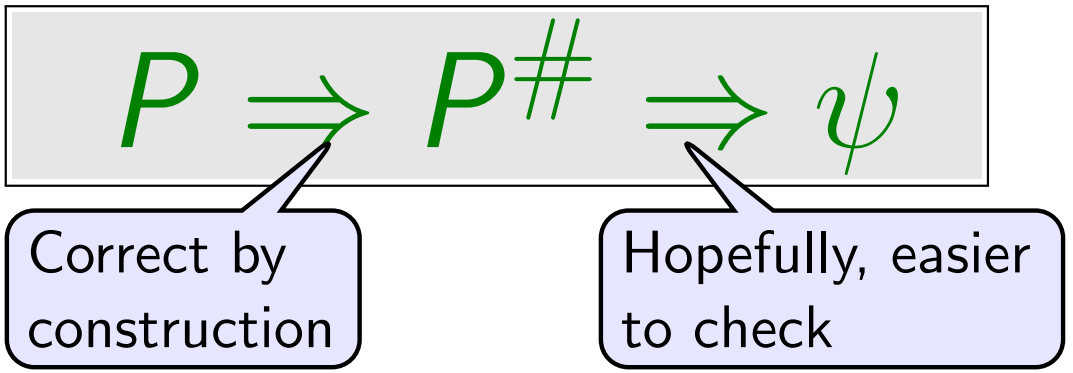

Example : program to CFG

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void main() {
 i = 0;
 while( i < 10 ) {
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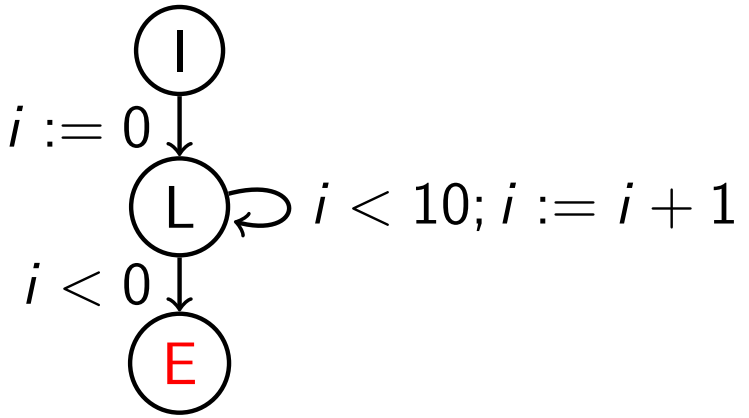

Example : CFG to abstract model

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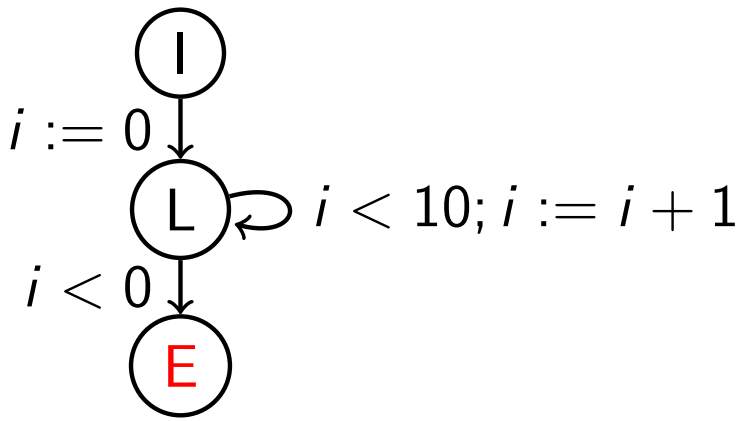

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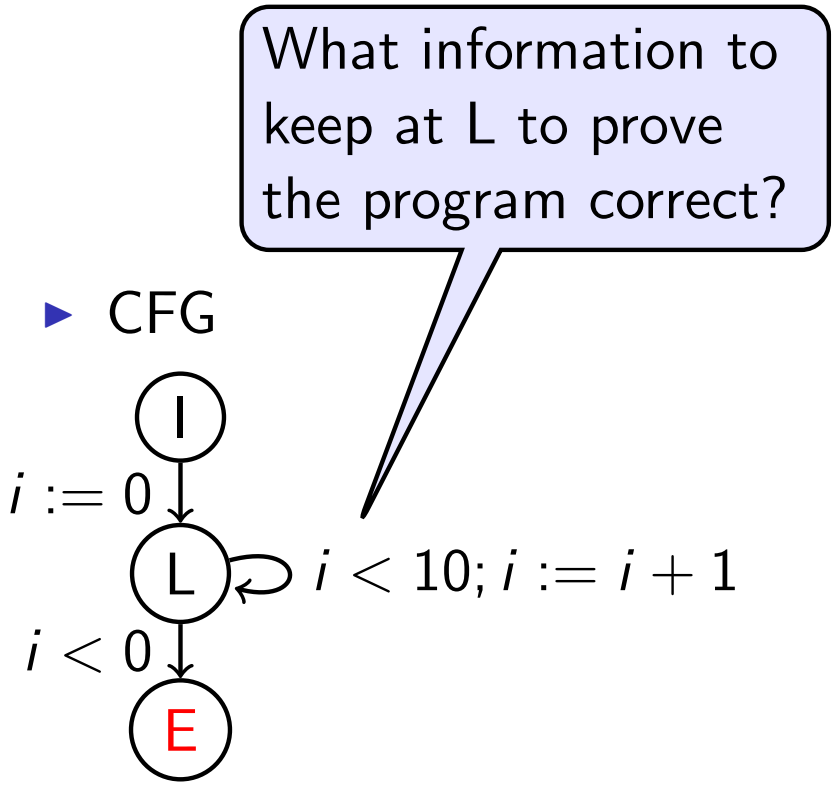

Example : CFG to abstract model

What information to keep at L to prove the program correct?

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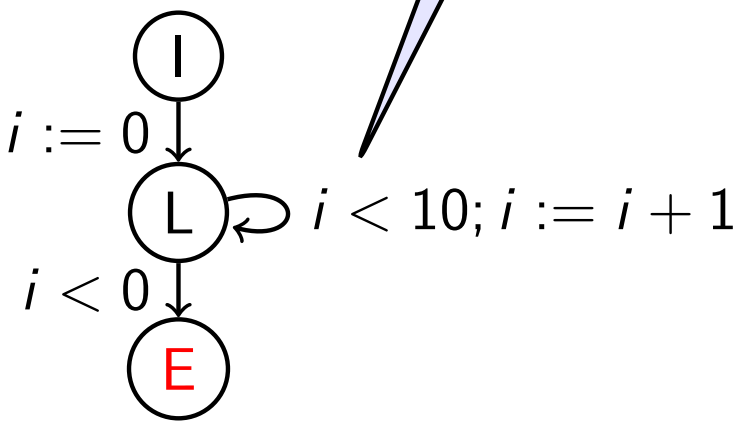

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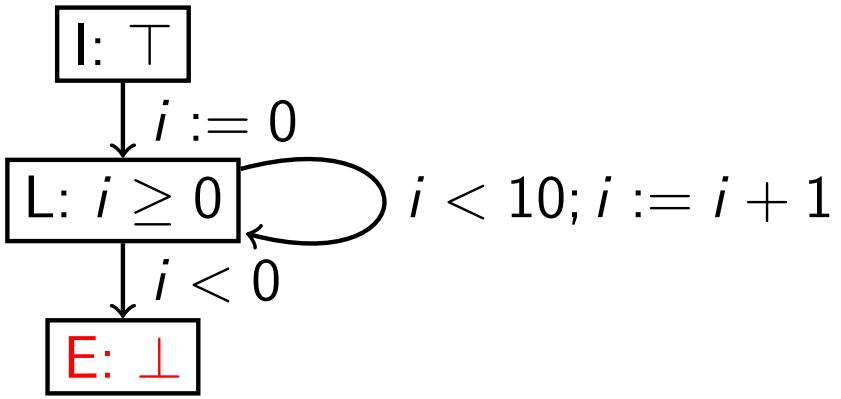

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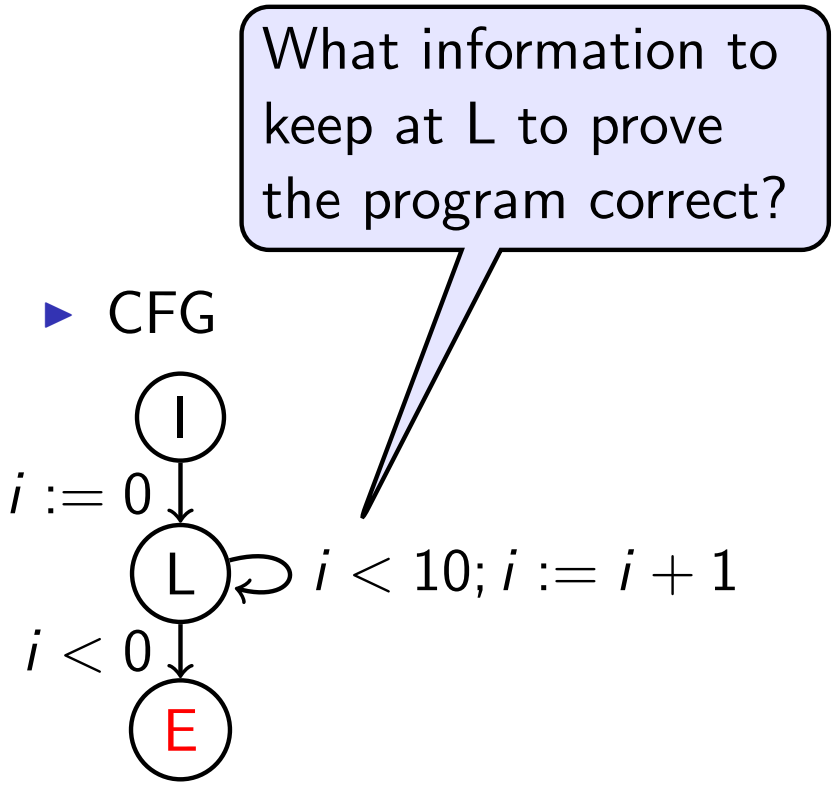

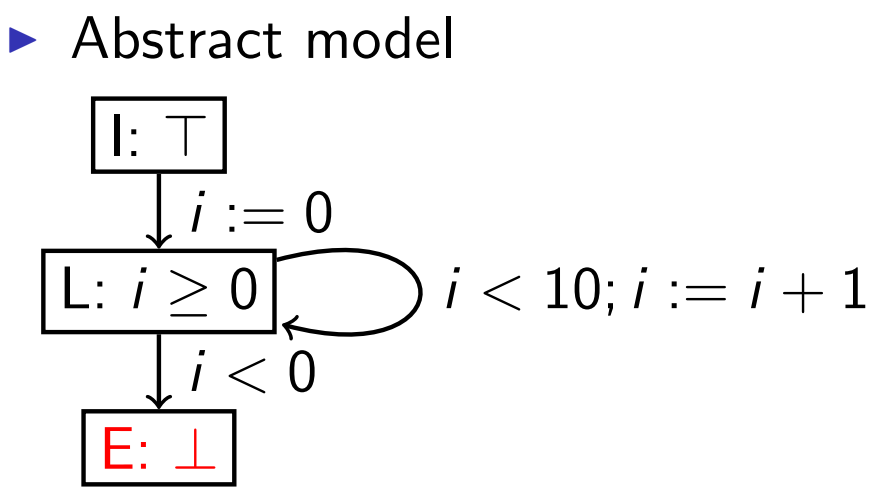

Verification problem $\equiv$ **find the right abstract model**

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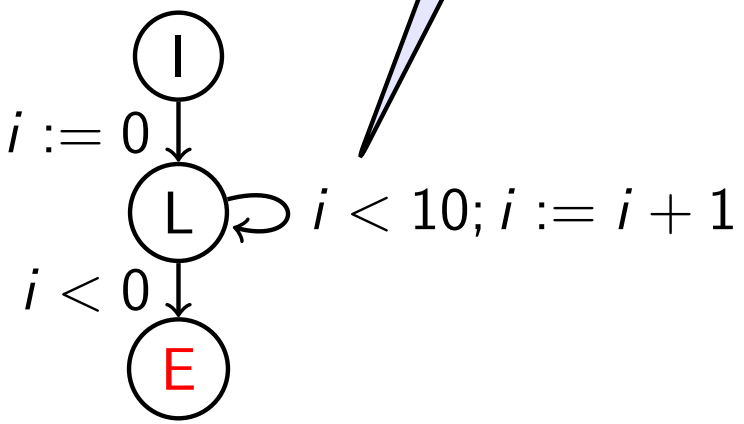

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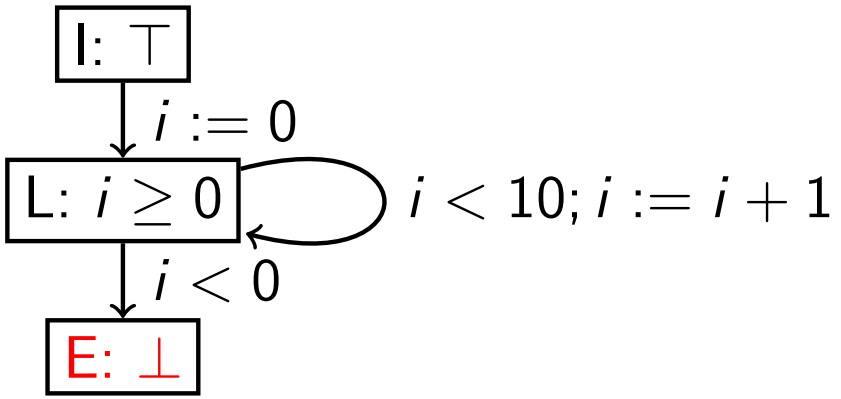

Verification problem $\equiv$ **find the right abstract model**

Verification methods only differ in how to find such an abstract model

Example : A verification method

CEGAR: CounterExample Guided Abstraction Refinement

Program

Example : A verification method

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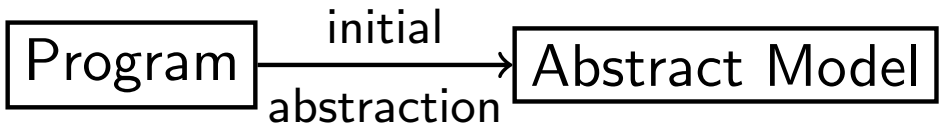

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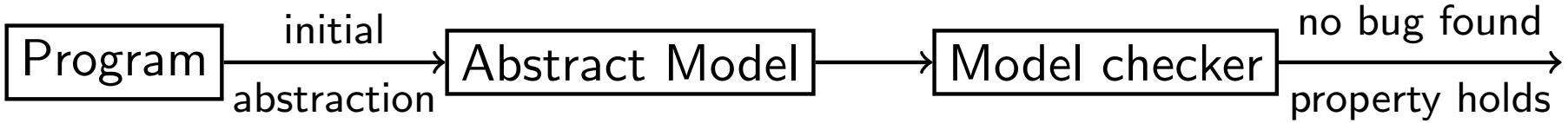

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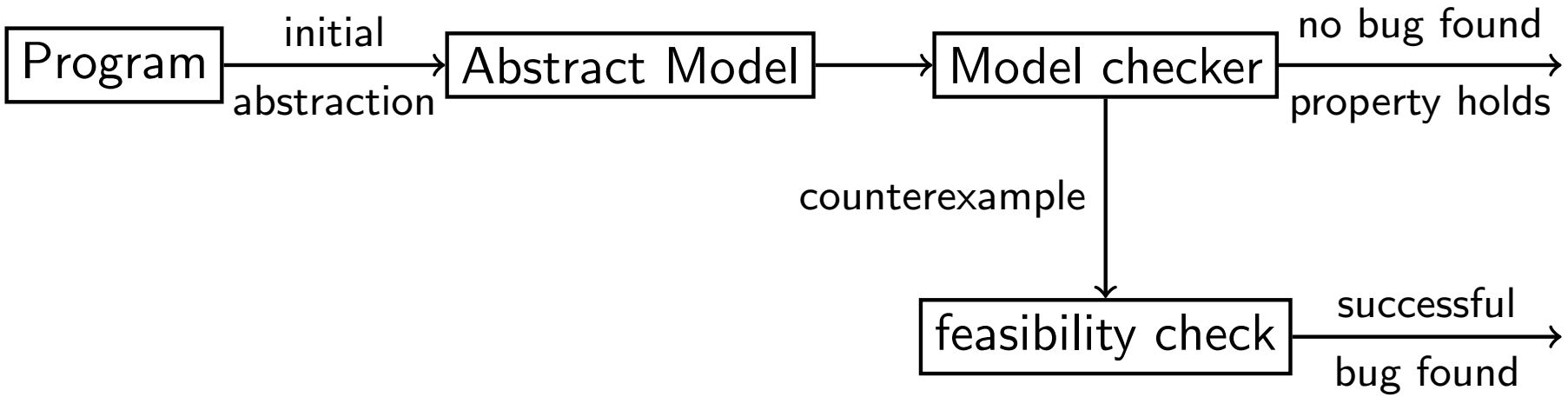

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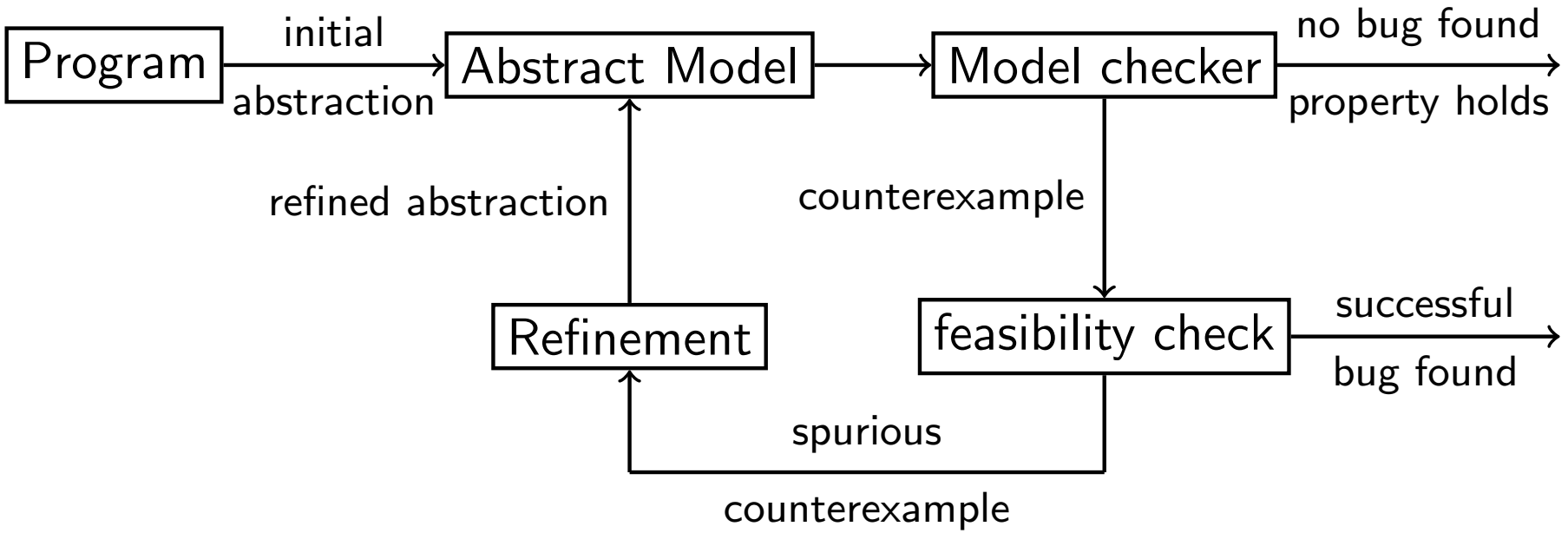

Topic 1.2

What is so hard about concurrency?

Schedule blowup

Exercise 1.1

What is the number of schedules between two threads with number of instructions N_1 and N_2 ?

Schedule blowup

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What is the number of schedules between two threads with number of instructions N_1 and N_2 ?

The blowup is not the only problem.

In the presence of synchronization primitives, the sets of allowed schedules appear deceptively simple, but are ugly beasts
e. g., locks, barriers, etc

Memory behavior

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Backend Thread

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result = r;
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Example 1.3

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Backend Thread		**Display Thread**
`r = calculate();`	‖	`while(ready == 0);`
`result = r;`		`print results;`
`ready = 1;`		

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In the concurrent world, threads may not have same view of memory!

Example 1.3

```
Global init result = 0, ready = 0;
```

Backend Thread		**Display Thread**
`r = calculate();`	$\parallel$	`while(ready == 0);`
`result = r;`		`print results;`
`ready = 1;`		

Will this program always print the result of the calculation?

Memory behavior

We usually believe that memory is sequential consistent.

In the concurrent world, threads may not have same view of memory!

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Backend Thread		**Display Thread**
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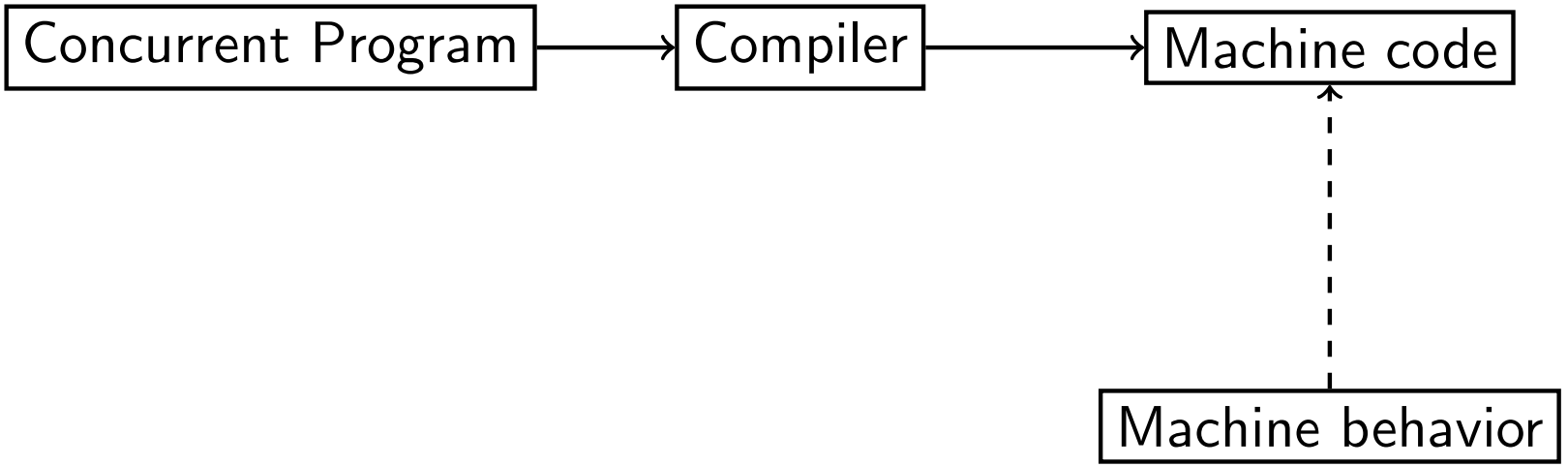
Will this program always print the result of the calculation?

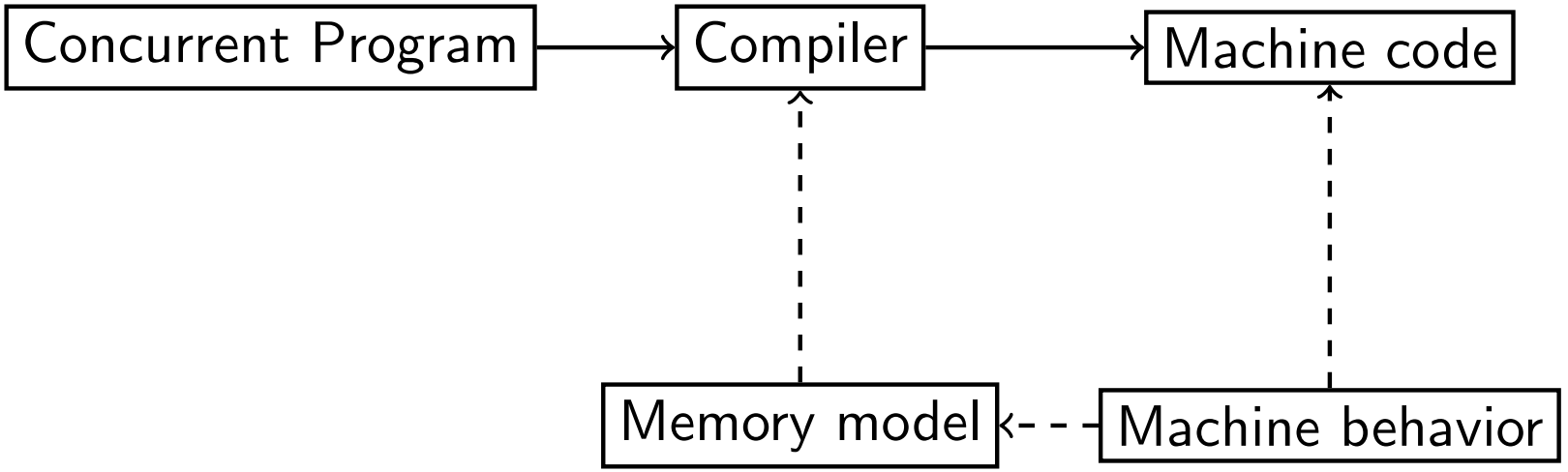
Writes overtake each other. The program is wrong on a typical smart phone!!

Memory models

Memory models



Memory models



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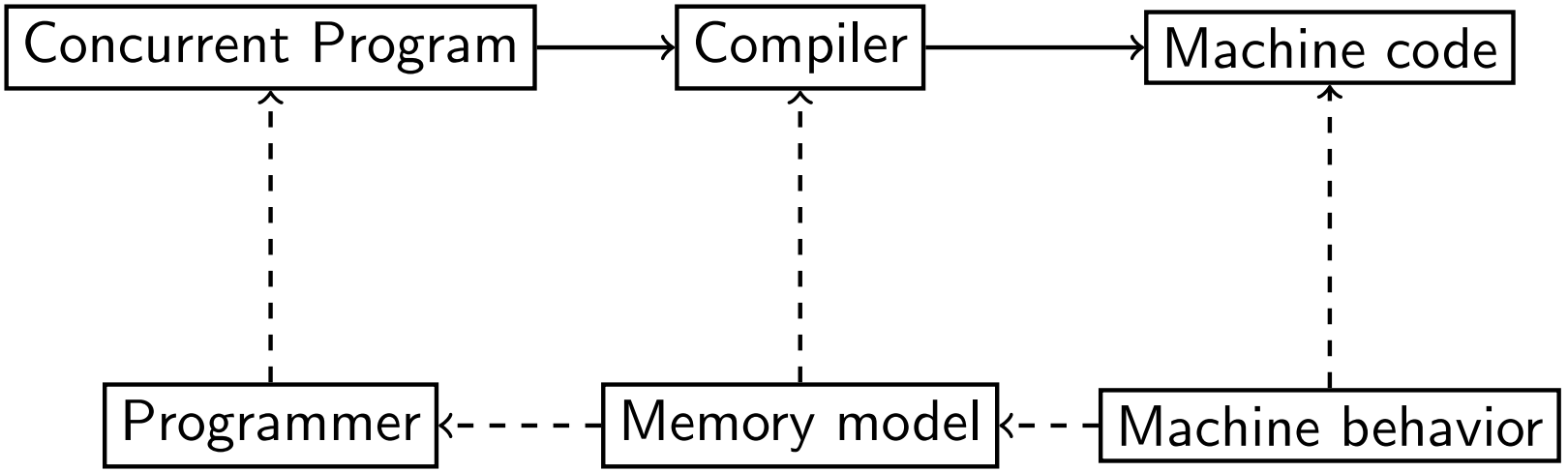

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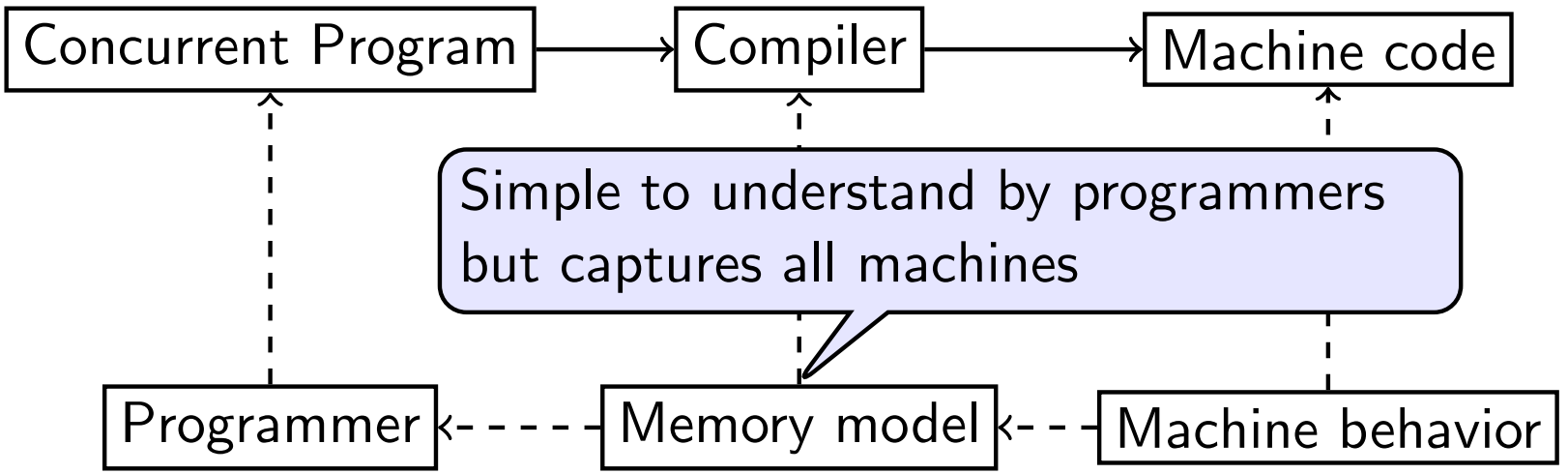

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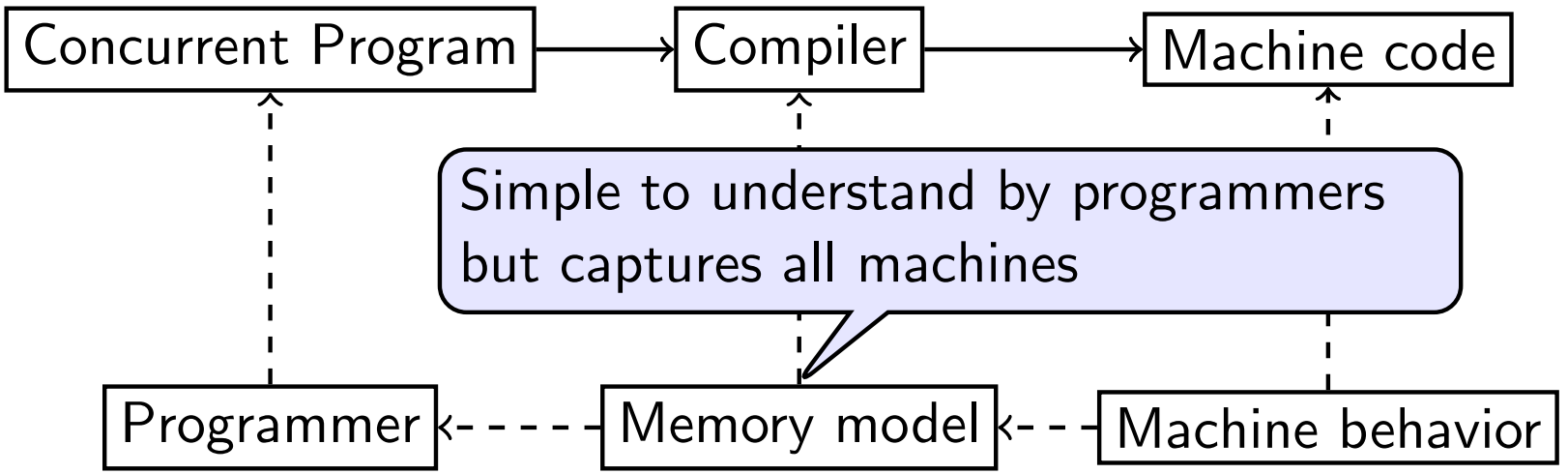

- C++11 publishes such a memory model
- Allows too many behaviors, even if no hardware exhibits them
- Disallows many simple compiler optimizations

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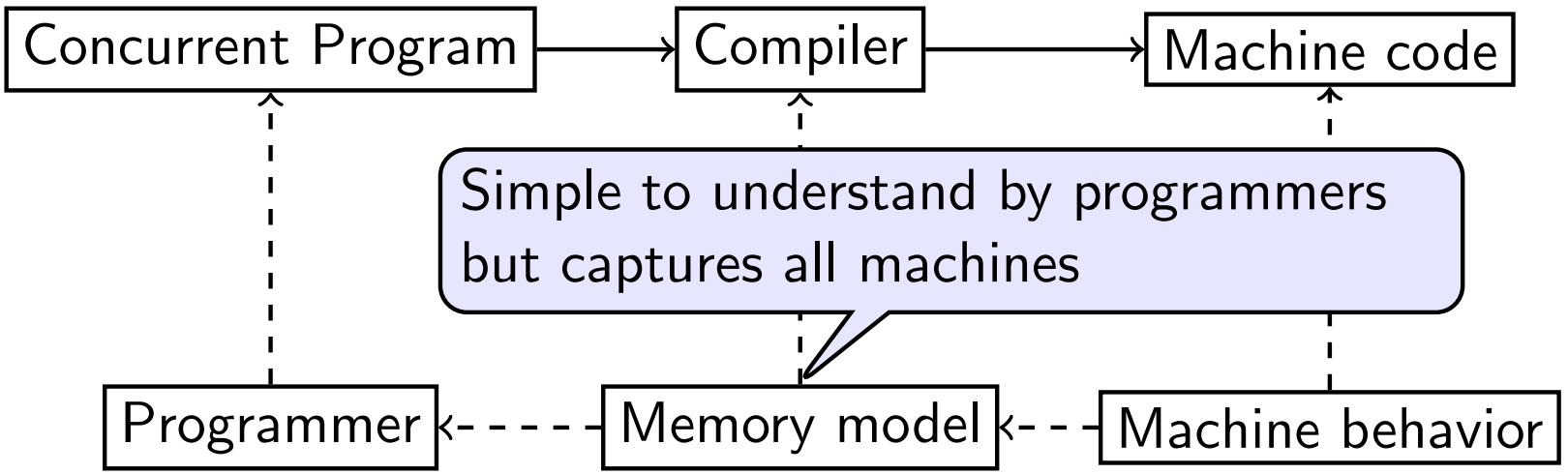

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- We are working on developing memory models that
  - is easy to understand
  - allows a good number of compiler optimization
  - allows efficient analysis of programs