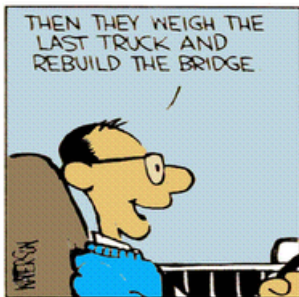
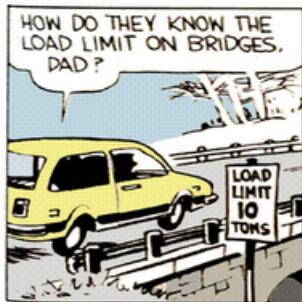


# Access Control and Privacy Policies (9)

Email: christian.urban at kcl.ac.uk

Office: S1.27 (1st floor Strand Building)

Slides: KEATS (also homework is there)



# Old-Fashioned Eng. vs. CS



## bridges:

engineers can “look” at a bridge and have a pretty good intuition about whether it will hold up or not (redundancy; predictive theory)



## code:

programmers have very little intuition about their code; often it is too expensive to have redundancy; not “continuous”

# Dijkstra on Testing

“Program testing can be a very effective way to show the presence of bugs, but it is hopelessly inadequate for showing their absence.”

unfortunately attackers exploit bugs (Satan's computer vs Murphy's)

Dijkstra: shortest path algorithm, dining philosophers problem, semaphores

# Proving Programs to be Correct

**Theorem:** There are infinitely many prime numbers.

**Proof ...**

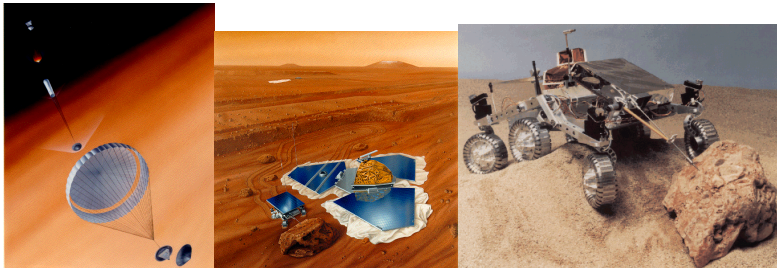
similarly

**Theorem:** The program is doing what it is supposed to be doing.

**Long, long proof ...**

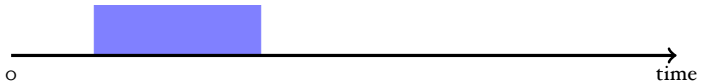
This can be a gigantic proof. The only hope is to have help from the computer. 'Program' is here to be understood to be quite general (protocol, OS,...).

# Mars Pathfinder Mission 1997



- despite NASA's famous testing procedures, the lander crashed frequently on Mars
- a scheduling algorithm was not used in the OS

low priority



high priority

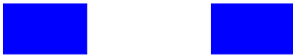


low priority

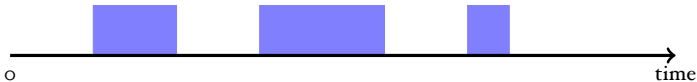




high priority



low priority

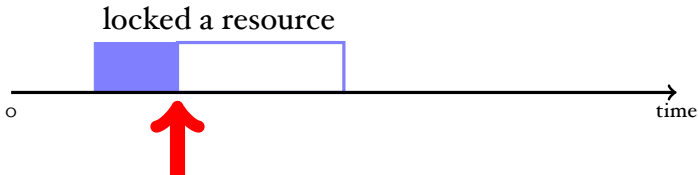


Scheduling: You want to avoid that a high priority process is staved indefinitely.

high priority



low priority



Scheduling: You want to avoid that a high priority process is staved indefinitely.

high priority



locked a resource

low priority

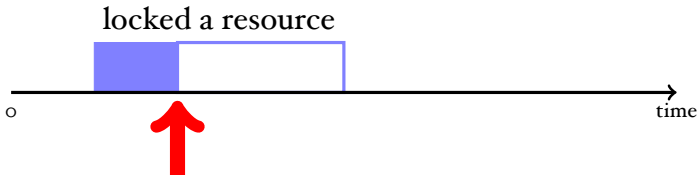


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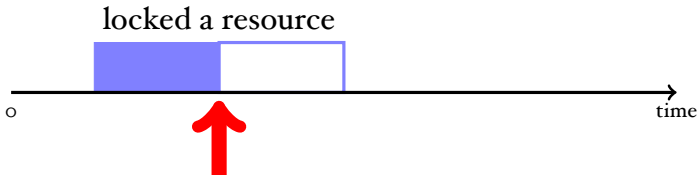


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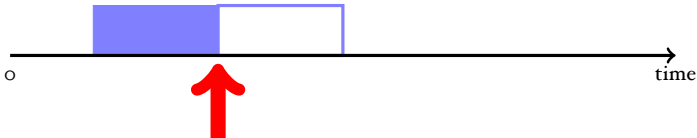


medium pr.



low priority

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o

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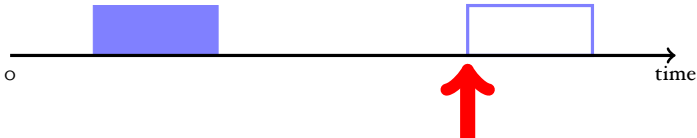


medium pr.



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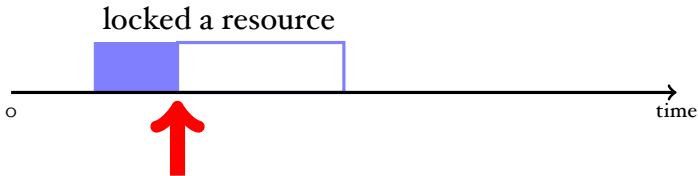
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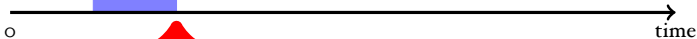
high priority



medium pr.



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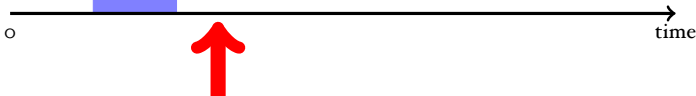
high priority



medium pr.



low priority

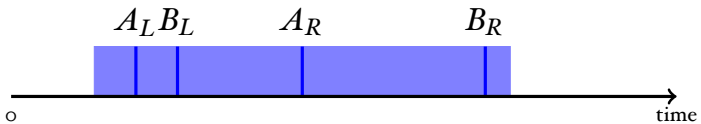


Scheduling: You want to avoid that a high priority process is staved indefinitely.

# Priority Inheritance Scheduling

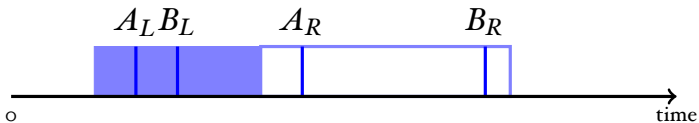
- Let a low priority process  $L$  temporarily inherit the high priority of  $H$  until  $L$  leaves the critical section unlocking the resource.
- Once the resource is unlocked  $L$  returns to its original priority level.

low priority



high priority

low priority

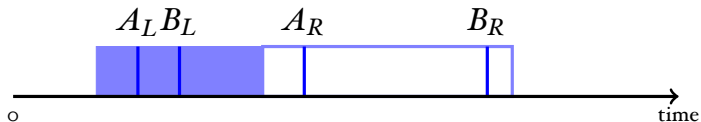




high priority



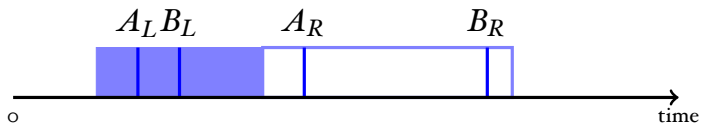
low priority



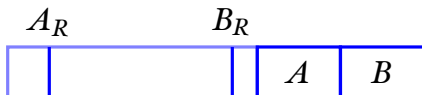
high priority



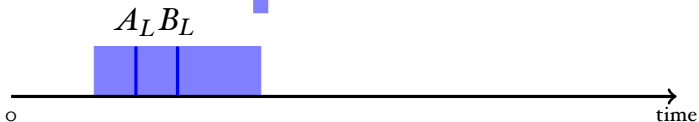
low priority



high priority



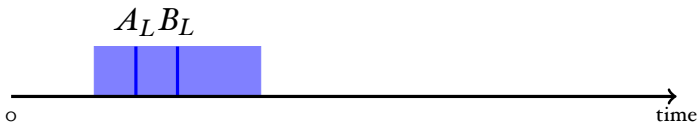
low priority



high priority



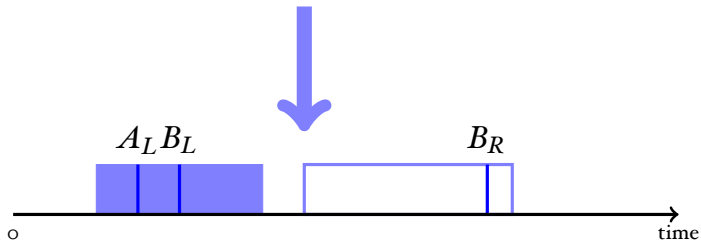
low priority



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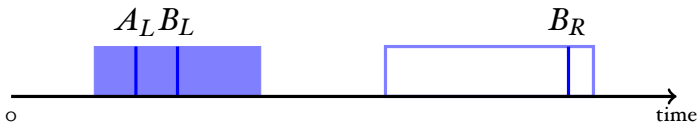
low priority



high priority



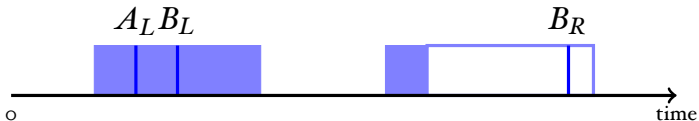
low priority

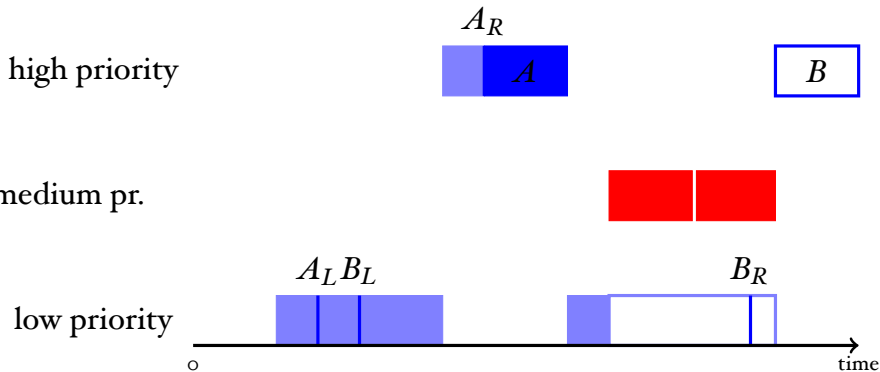


high priority

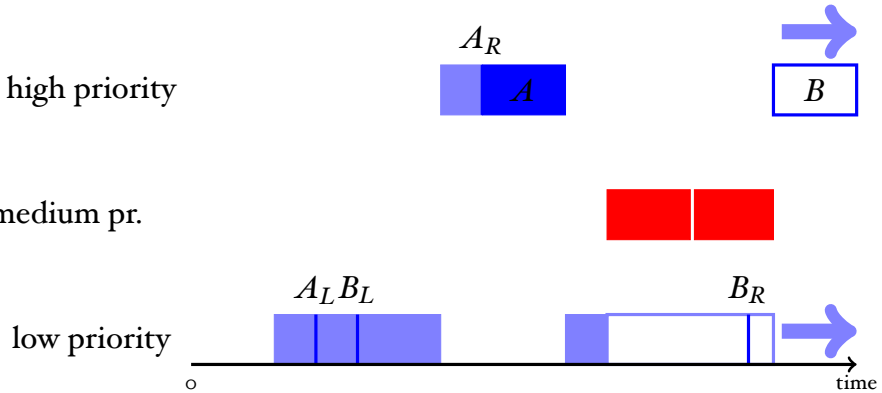


low priority









Scheduling: You want to avoid that a high priority process is staved indefinitely.

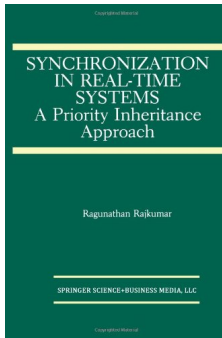
# Priority Inheritance Scheduling

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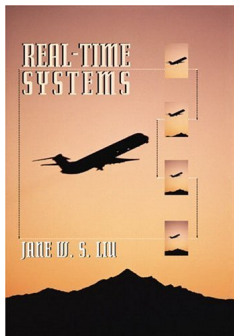
# Priority Inheritance Scheduling

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- ... $L$  needs to switch to the highest **remaining** priority of the threads that it blocks.

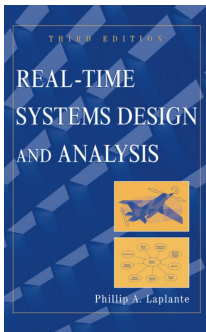
this error is already known since around 1999



- by Rajkumar, 1991
- *“it resumes the priority it had at the point of entry into the critical section”*



- by Jane Liu, 2000
- *“The job  $J_1$  executes at its inherited priority until it releases  $R$ ; at that time, the priority of  $J_1$  returns to its priority at the time when it acquires the resource  $R$ .”*
- gives pseudo code and totally bogus data structures
- interesting part *“left as an exercise”*



- by Laplante and Ovaska, 2011 (\$113.76)
- *“when [the task] exits the critical section that caused the block, it reverts to the priority it had when it entered that section”*

# Priority Scheduling

- a scheduling algorithm that is widely used in real-time operating systems
- has been “proved” correct by hand in a paper in 1983
- but this algorithm turned out to be incorrect, despite its “proof”

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- a scheduling algorithm that is widely used in real-time operating systems
- has been “proved” correct by hand in a paper in 1983
- but this algorithm turned out to be incorrect, despite its “proof”
- we corrected the algorithm and then **really** proved that it is correct
- we implemented this algorithm in a small OS called PINTOS (used for teaching at Stanford)
- our implementation was much more efficient than their reference implementation

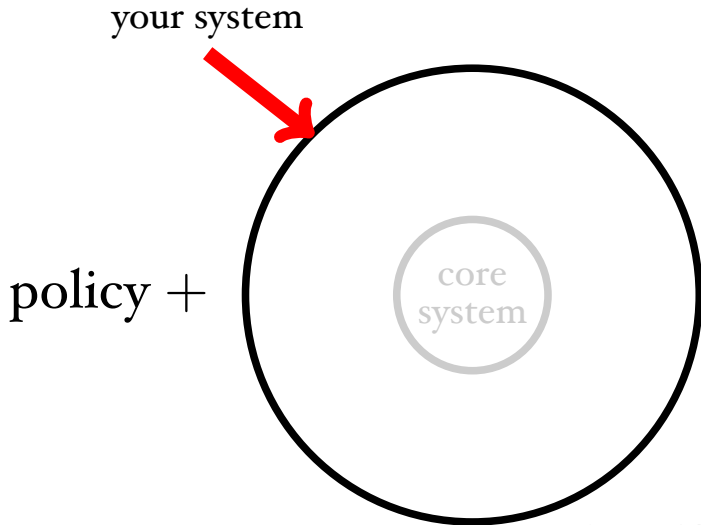


# Design of AC-Policies

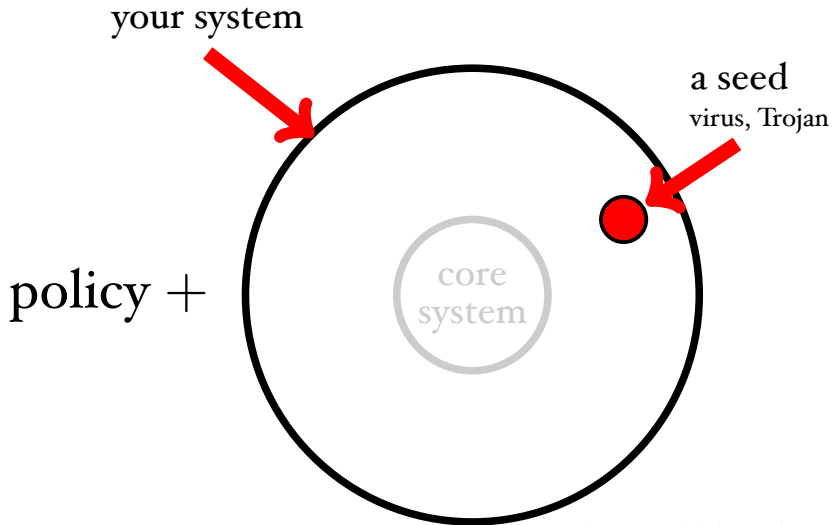
*“what you specify is what you get but not necessarily what you want...”*

main work by Chunhan Wu (PhD-student)

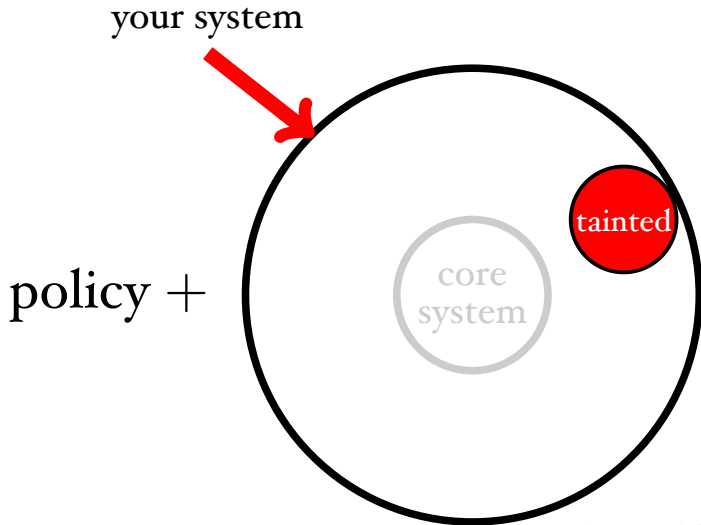
# Testing Policies



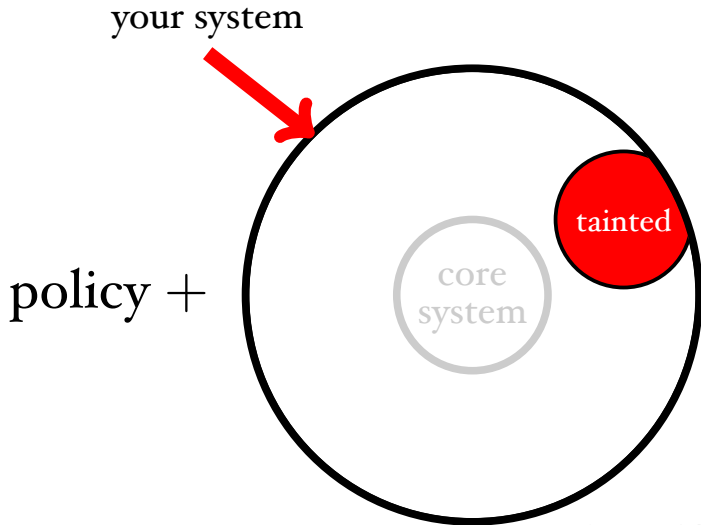
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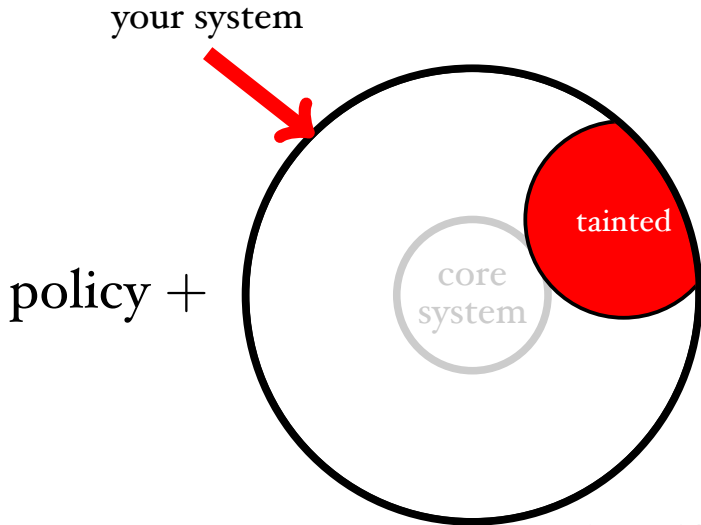
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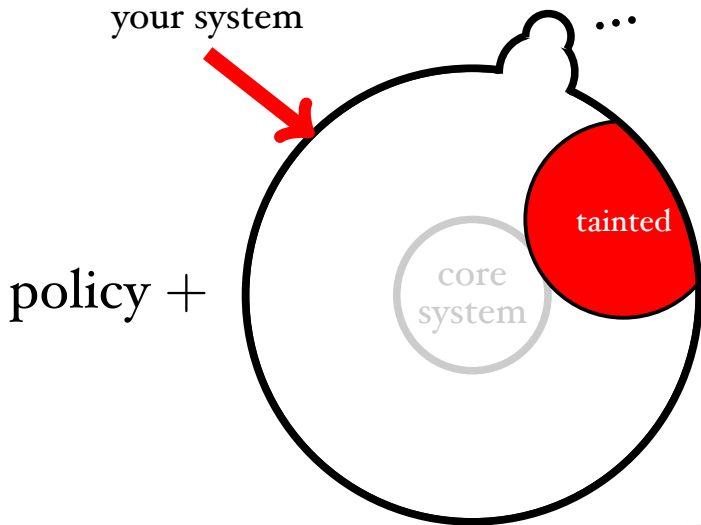
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# Testing Policies



# A Sound and Complete Test

- working purely in the *dynamic world* does not work – infinite state space
- working purely on *static* policies also does not work – because of over approximation
  - suppose a tainted file has type *bin* and
  - there is a role *r* which can both read and write *bin*-files



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  - but if there is no process with role *r* and it will never been created, then the file actually does not spread
- **our solution:** take a middle ground and record precisely the information of the initial state, but be less precise about every newly created object.

# Big Proofs in CS

Formal proofs in CS sound like science fiction?  
Completely irrelevant! Lecturer gone mad?

# Big Proofs in CS

Formal proofs in CS sound like science fiction?  
Completely irrelevant! Lecturer gone mad?

- in 2008, verification of a small C-compiler
  - “if my input program has a certain behaviour, then the compiled machine code has the same behaviour”
  - is as good as `gcc -O1`, but much less buggy
- in 2010, verification of a micro-kernel operating system (approximately 8700 loc)
  - 200k loc of proof
  - 25 - 30 person years
  - found 160 bugs in the C code (144 by the proof)

# Goal

Remember the Bridges example?

- Can we look at our programs and somehow ensure they are secure/bug free/correct?

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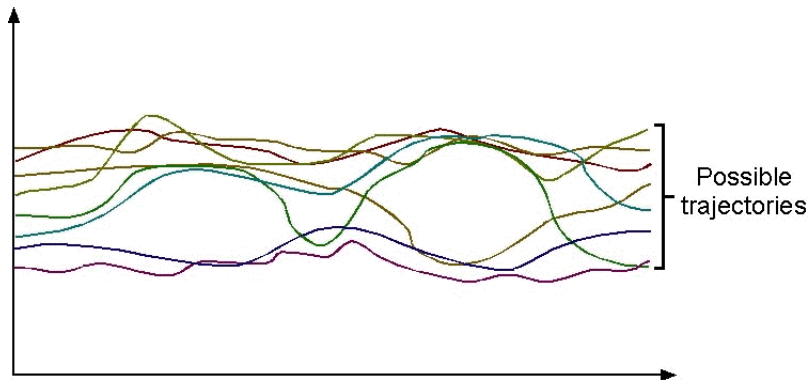
# Goal

Remember the Bridges example?

- Can we look at our programs and somehow ensure they are secure/bug free/correct?
- Very hard: Anything interesting about programs is equivalent to halting problem, which is undecidable.
- **Solution:** We avoid this “minor” obstacle by being as close as possible of deciding the halting problem, without actually deciding the halting problem.  $\Rightarrow$  static analysis

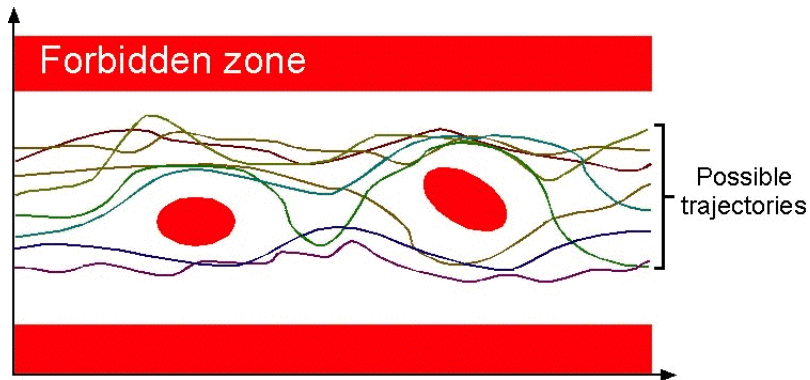


# What is Static Analysis?

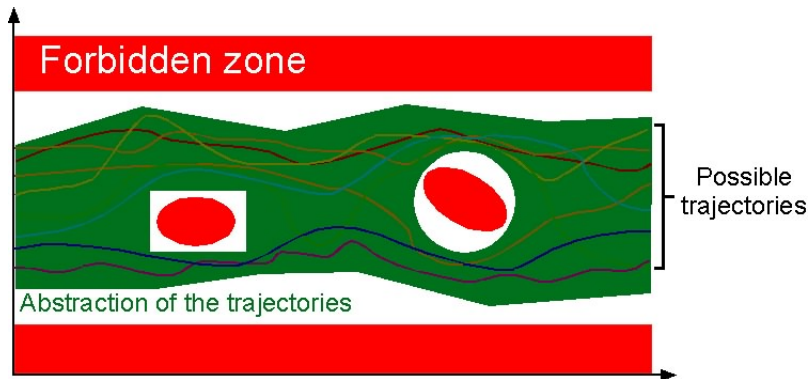


- depending on some initial input, a program (behaviour) will “develop” over time.

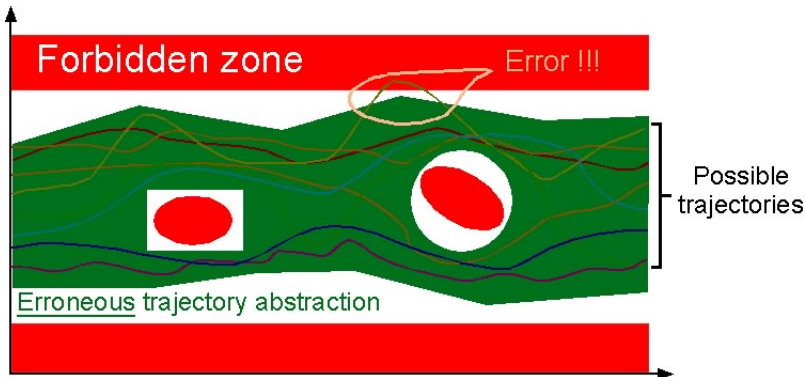
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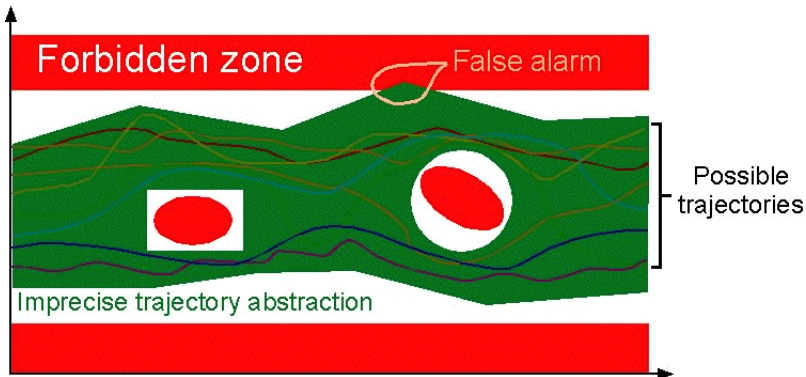


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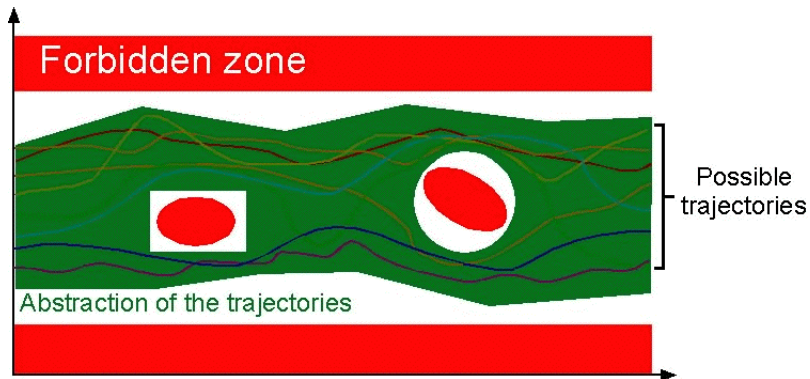
- to be avoided

# What is Static Analysis?



- this needs more work

# What is Static Analysis?



# Concrete Example: Sign-Analysis

$$\begin{aligned} \langle \text{Exp} \rangle &::= \langle \text{Exp} \rangle + \langle \text{Exp} \rangle \\ &| \langle \text{Exp} \rangle * \langle \text{Exp} \rangle \\ &| \langle \text{Exp} \rangle = \langle \text{Exp} \rangle \\ &| \langle \text{num} \rangle \\ &| \langle \text{var} \rangle \\ \langle \text{Stmt} \rangle &::= \langle \text{label} \rangle : \\ &| \langle \text{var} \rangle := \langle \text{Exp} \rangle \\ &| \text{jmp? } \langle \text{Exp} \rangle \langle \text{label} \rangle \\ &| \text{goto } \langle \text{label} \rangle \\ \langle \text{Prog} \rangle &::= \langle \text{Stmt} \rangle \dots \end{aligned}$$

# Concrete Example: Sign-Analysis

$\langle \text{Exp} \rangle ::= \langle \text{Exp} \rangle + \langle \text{Exp} \rangle$   
|  $\langle \text{Exp} \rangle * \langle \text{Exp} \rangle$   
|  $\langle \text{Exp} \rangle = \langle \text{Exp} \rangle$   
|  $\langle \text{num} \rangle$   
|  $\langle \text{var} \rangle$

$\langle \text{Stmt} \rangle ::= \langle \text{label} \rangle :$   
|  $\langle \text{var} \rangle := \langle \text{Exp} \rangle$   
|  $\text{jmp? } \langle \text{Exp} \rangle \langle \text{label} \rangle$   
|  $\text{goto } \langle \text{label} \rangle$

$\langle \text{Prog} \rangle ::= \langle \text{Stmt} \rangle \dots$

```
a := 1
n := 5
top: jmp? n = 0 done
     a := a * n
     n := n + -1
     goto top
done:
```



# Concrete Example: Sign-Analysis

$\langle \text{Exp} \rangle ::= \langle \text{Exp} \rangle + \langle \text{Exp} \rangle$   
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|  $\text{goto } \langle \text{label} \rangle$   
 $\langle \text{Prog} \rangle ::= \langle \text{Stmt} \rangle \dots$

```
n := 6
m1 := 0
m2 := 1
top: jmp? n = 0 done
     tmp := m2
     m2 := m1 + m2
     m1 := tmp
     n := n + -1
     goto top
done:
```

# Eval

$[n]_{env}$	$\stackrel{\text{def}}{=} n$
$[x]_{env}$	$\stackrel{\text{def}}{=} env(x)$
$[e_1 + e_2]_{env}$	$\stackrel{\text{def}}{=} [e_1]_{env} + [e_2]_{env}$
$[e_1 * e_2]_{env}$	$\stackrel{\text{def}}{=} [e_1]_{env} * [e_2]_{env}$
$[e_1 = e_2]_{env}$	$\stackrel{\text{def}}{=} \begin{cases} 1 & \text{if } [e_1]_{env} = [e_2]_{env} \\ 0 & \text{otherwise} \end{cases}$

```
def eval_exp(e: Exp, env: Env) : Int = e match {  
  case Num(n) => n  
  case Var(x) => env(x)  
  case Plus(e1, e2) => eval_exp(e1, env) + eval_exp(e2, env)  
  case Times(e1, e2) => eval_exp(e1, env) * eval_exp(e2, env)  
  case Equ(e1, e2) =>  
    if (eval_exp(e1, env) == eval_exp(e2, env)) 1 else 0  
}
```

## A program

```
    a := 1
    n := 5
top:  jmp? n = 0 done
      a := a * n
      n := n + -1
      goto top
done:
```

## Some snippets

```
"""
    a := 1
    n := 5
top:  jmp? n = 0 done
      a := a * n
      n := n + -1
      goto top
done:
```

```
top:  jmp? n = 0 done
      a := a * n
      n := n + -1
      goto top
done:
```

```
done:
```

# Eval for Stmts

Let  $sn$  be the snippets of a program

$$[nil]_{env} \stackrel{\text{def}}{=} env$$

$$[Label(l) :: rest]_{env} \stackrel{\text{def}}{=} [rest]_{env}$$

$$[x := e :: rest]_{env} \stackrel{\text{def}}{=} [rest]_{(env[x:=e]_{env})}$$

$$[jmp? e l :: rest]_{env} \stackrel{\text{def}}{=} \begin{cases} [sn(l)]_{env} & \text{if } [e]_{env} = \mathbf{I} \\ [rest]_{env} & \text{otherwise} \end{cases}$$

$$[goto l :: rest]_{env} \stackrel{\text{def}}{=} [sn(l)]_{env}$$

Start with  $[sn(“”)]_{\emptyset}$

# Eval in Code

```
def eval(sn: Snips) : Env = {  
  def eval_stmts(sts: Stmts, env: Env) : Env = sts match {  
    case Nil => env  
    case Label(l)::rest => eval_stmts(rest, env)  
    case Assign(x, e)::rest =>  
      eval_stmts(rest, env + (x -> eval_exp(e, env)))  
    case Jmp(b, l)::rest =>  
      if (eval_exp(b, env) == 1) eval_stmts(sn(l), env)  
      else eval_stmts(rest, env)  
    case Goto(l)::rest => eval_stmts(sn(l), env)  
  }  
  
  eval_stmts(sn("""), Map())  
}
```

# The Idea

```
a := 1
n := 5
top: jmp? n = 0 done
     a := a * n
     n := n + -1
     goto top
done:
```



```
a := '+'
n := '+'
top: jmp? n = '0' done
     a := a * n
     n := n + '- '
     goto top
done:
```

Replace all constants and variables by either +, - or 0. What we want to find out is what the sign of a and n is (they are always positive).

# Sign Analysis?

$e_1$	$e_2$	$e_1 + e_2$	$e_1$	$e_2$	$e_1 * e_2$
-	-	-	-	-	+
-	0	-	-	0	0
-	+	-, 0, +	-	+	-
0	x	x	0	x	0
+	-	-, 0, +	+	-	-
+	0	+	+	0	0
+	+	+	+	+	+

$$[n]_{env} \stackrel{\text{def}}{=} \begin{cases} \{+\} & \text{if } n > 0 \\ \{-\} & \text{if } n < 0 \\ \{0\} & \text{if } n = 0 \end{cases}$$

$$[x]_{env} \stackrel{\text{def}}{=} env(x)$$

$$[e_1 + e_2]_{env} \stackrel{\text{def}}{=} [e_1]_{env} \oplus [e_2]_{env}$$

$$[e_1 * e_2]_{env} \stackrel{\text{def}}{=} [e_1]_{env} \otimes [e_2]_{env}$$

$$[e_1 = e_2]_{env} \stackrel{\text{def}}{=} \{0, +\}$$

```
def aeval_exp(e: Exp, aenv: AEnv) : Set[Abst] = e match {
  case Num(0) => Set(Zero)
  case Num(n) if (n < 0) => Set(Neg)
  case Num(n) if (n > 0) => Set(Pos)
  case Var(x) => aenv(x)
  case Plus(e1, e2) =>
    aplus(aeval_exp(e1, aenv), aeval_exp(e2, aenv))
  case Times(e1, e2) =>
    atimes(aeval_exp(e1, aenv), aeval_exp(e2, aenv))
  case Equ(e1, e2) => Set(Zero, Pos)
}
```



# Sign Analysis

- We want to find out whether  $a$  and  $n$  are always positive?
- After a few optimisations, we can indeed find this out.
  - `if` returns  $+$  or  $\emptyset$
  - branch into only one direction if you know
  - if  $x$  is  $+$ , then  $x + -1$  cannot be negative
- What is this good for? Well, you do not need underflow checks (in order to prevent buffer-overflow attacks).