On algorithms operating in adversarial conditions

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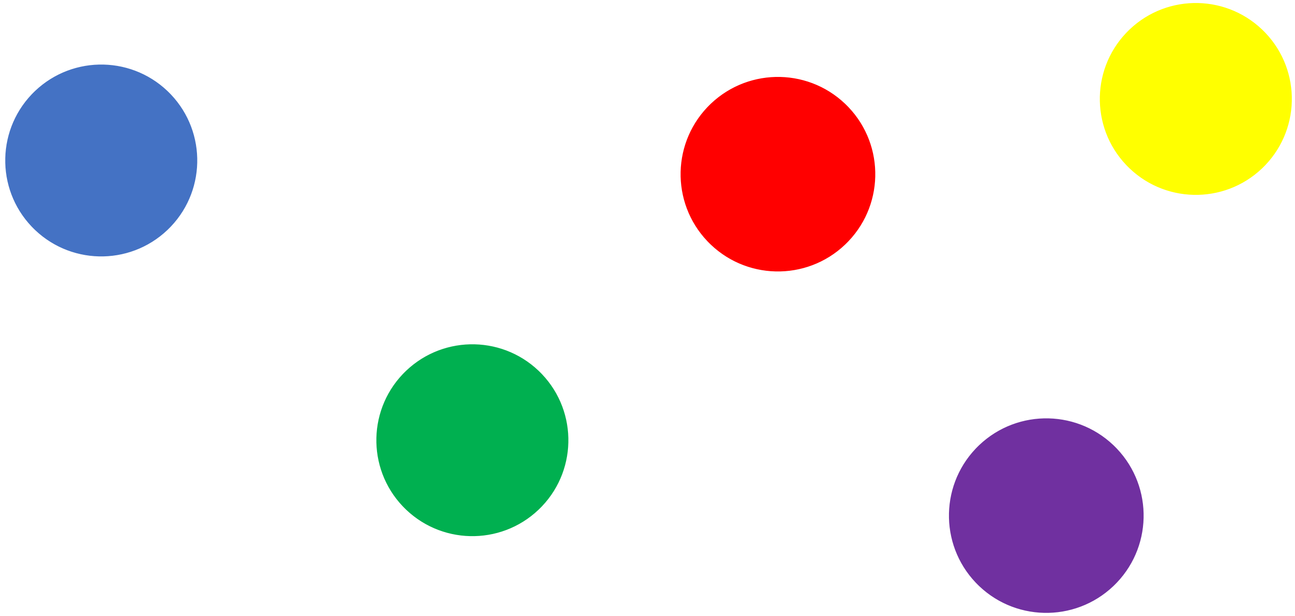
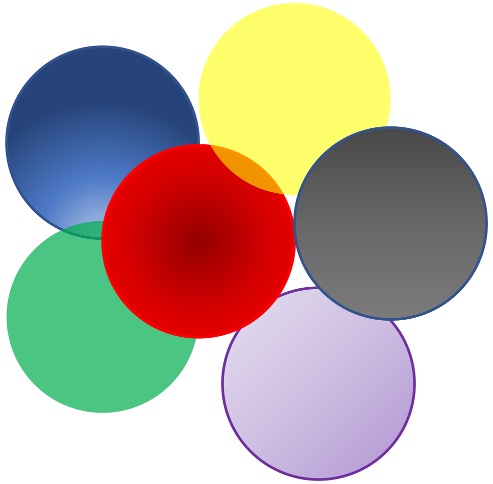
A Bottom-Up Process of Knowledge Generation:



Stage 1: Simple building blocks

A Bottom-Up Process of Knowledge Generation:



Stage 2: Complexity Introduced

A Bottom-Up Process of Knowledge Generation:

Stage 3: Complexity Maturing

A Bottom-Up Process of Knowledge Generation

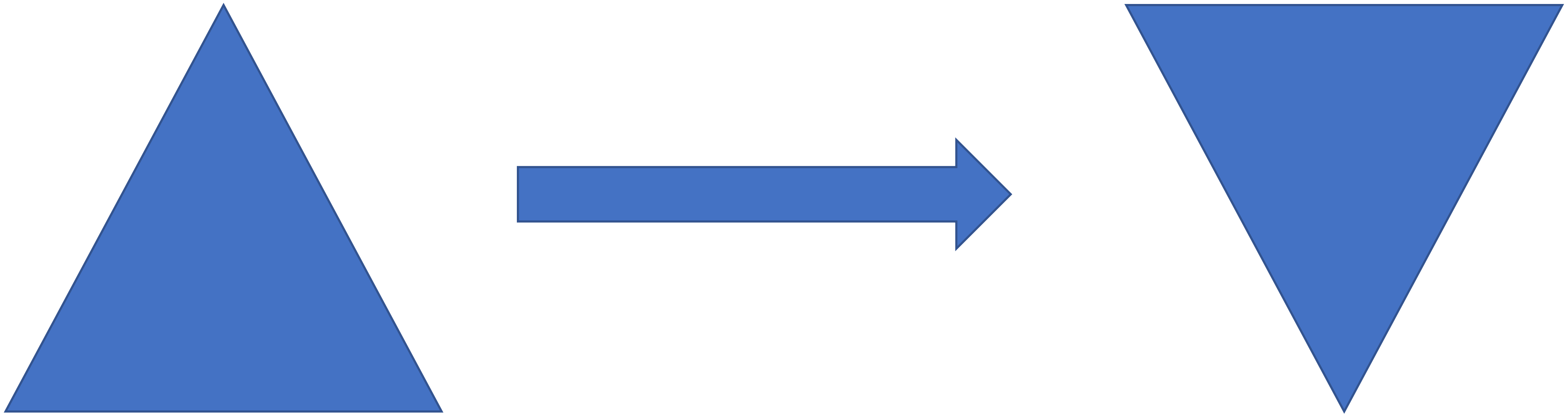
Stage 4: Complexity Celebrated

A Bottom-Up Process of Knowledge Generation:

Stage 5: Complexity Subsumed

A Bottom-Up Process of Knowledge Generation:

Stage 6: Building Blocks Rejected

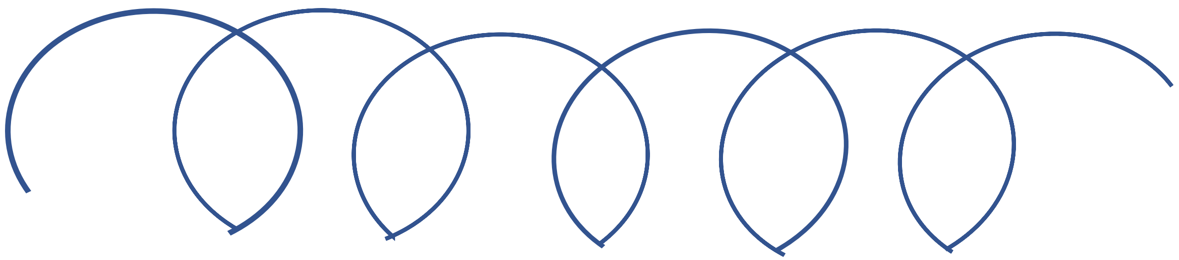


Bottom-Up Knowledge Generation

Top-Down Knowledge Generation

We often think of knowledge as evolving like this:

When it actually goes more like this:



What are our building blocks for thinking about algorithms?

What implicit assumptions are inherent in our abstractions?

Are these assumptions reasonable? Are they avoidable?

“Algorithms are Recipes”

We conceptualize an algorithm as a sequence of steps

If you follow the steps, you perform an intended function from inputs to outputs

Algorithms -> functions is a many-to-one mapping

The environment as ideal

Basic metrics of algorithm evaluation

- Correctness
- Running Time
- Memory Usage
- Parallel vs. Sequential
- Distributed vs. centralized
- Robustness to error (mostly in the distributed setting)

Testing An Algorithm

- We tend to think of testing implemented algorithms as testing function correctness and resource use:

  - Does the code give the right answer on average cases?
  - Does the code give the right answer on edge cases?
  - What is its run time on average cases?
  - What is it run time on worst cases?
  - What is it memory usage? Etc.

An ”ideal” test suite can catch any incorrect function evaluations, no matter how rare.

What we are neglecting here is the algorithm’s environment!

The environment as non-ideal

The environment as malicious

What deeply ingrained assumptions are likely to be violated?

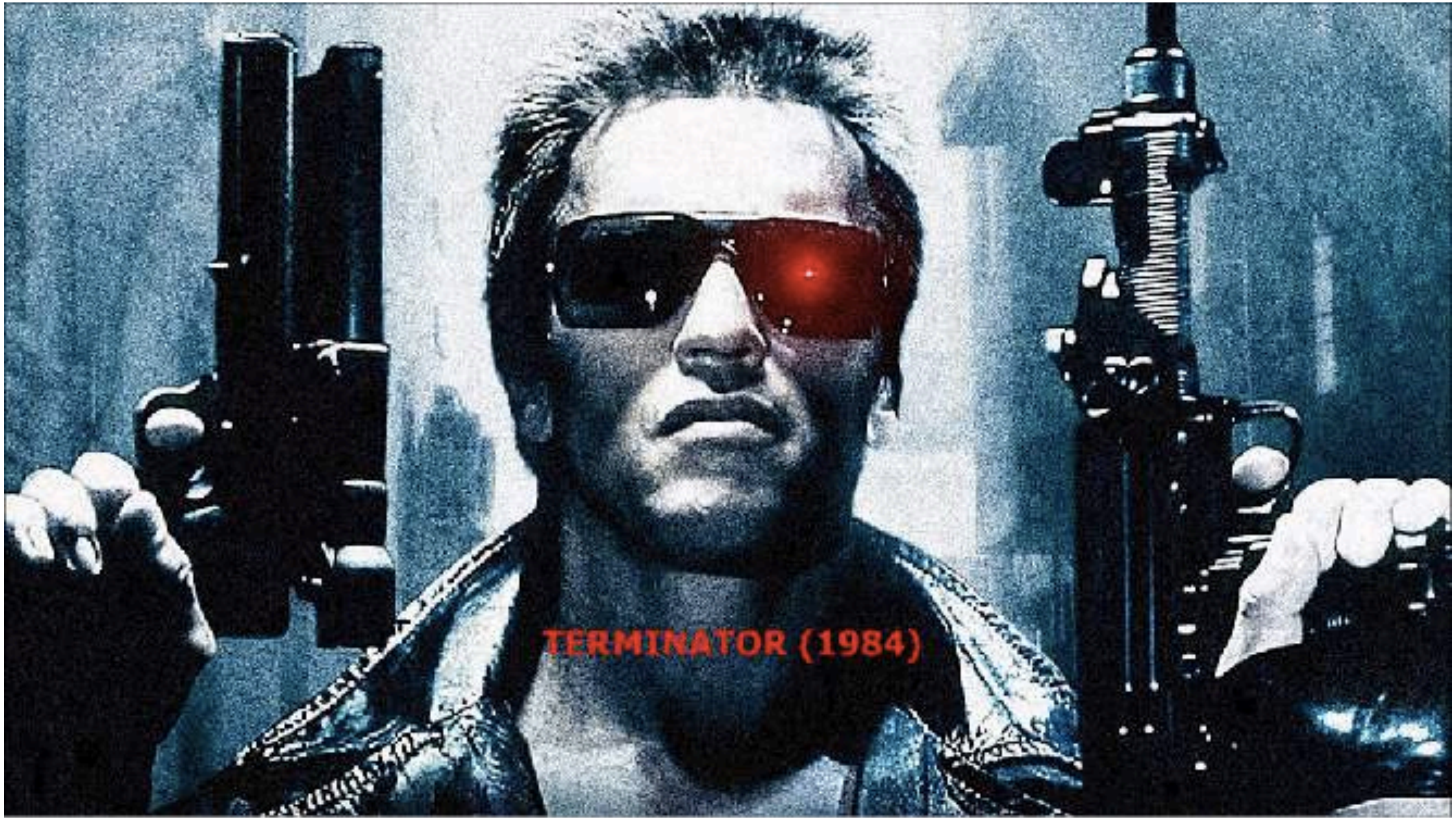
- External Inputs will conform to expectations
- Good Code will produce only good outcomes
- Code will run in isolation
- Code will run sequentially

"Algorithms are People Too"

- They get interrupted
- They get quoted out of context
- They are under surveillance

"You'd be lucky to get him to work for you"

We are *not* talking about AI…



On Interruption …

Common Problem: User Input

Account number	username
1	bah52
2	abb31
3	mnd17
4	asifek4#$asdf$!349$t45sdfg0%60$349…

> enter username with 3 letters and 2 numbers

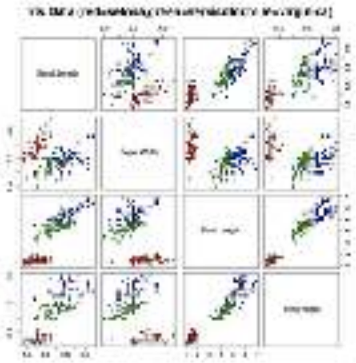
> asifek4#$asdf$!349$t45sdfg0%60$349…

What happens when user input doesn't conform to our expectations?

Buffer Overflow/ SQL Injection

In our imaginations:

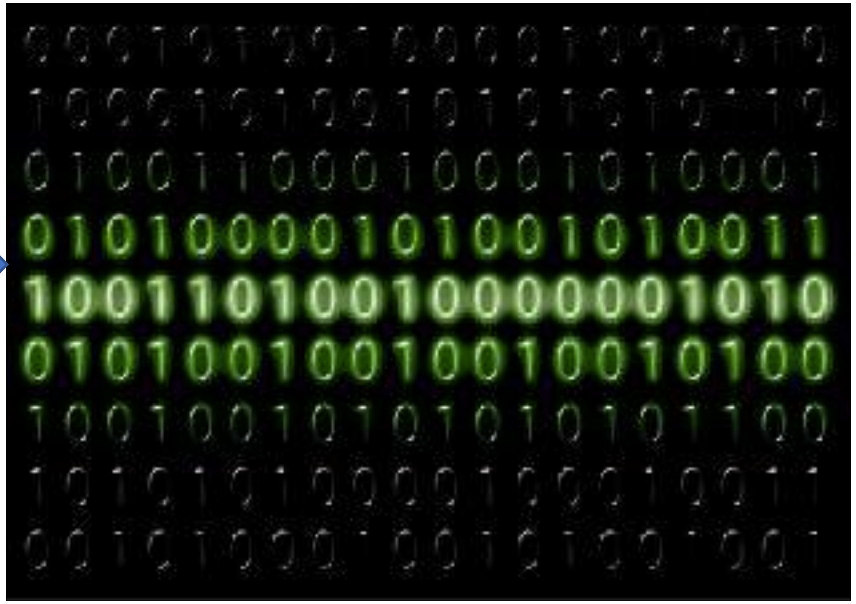
Data



Code

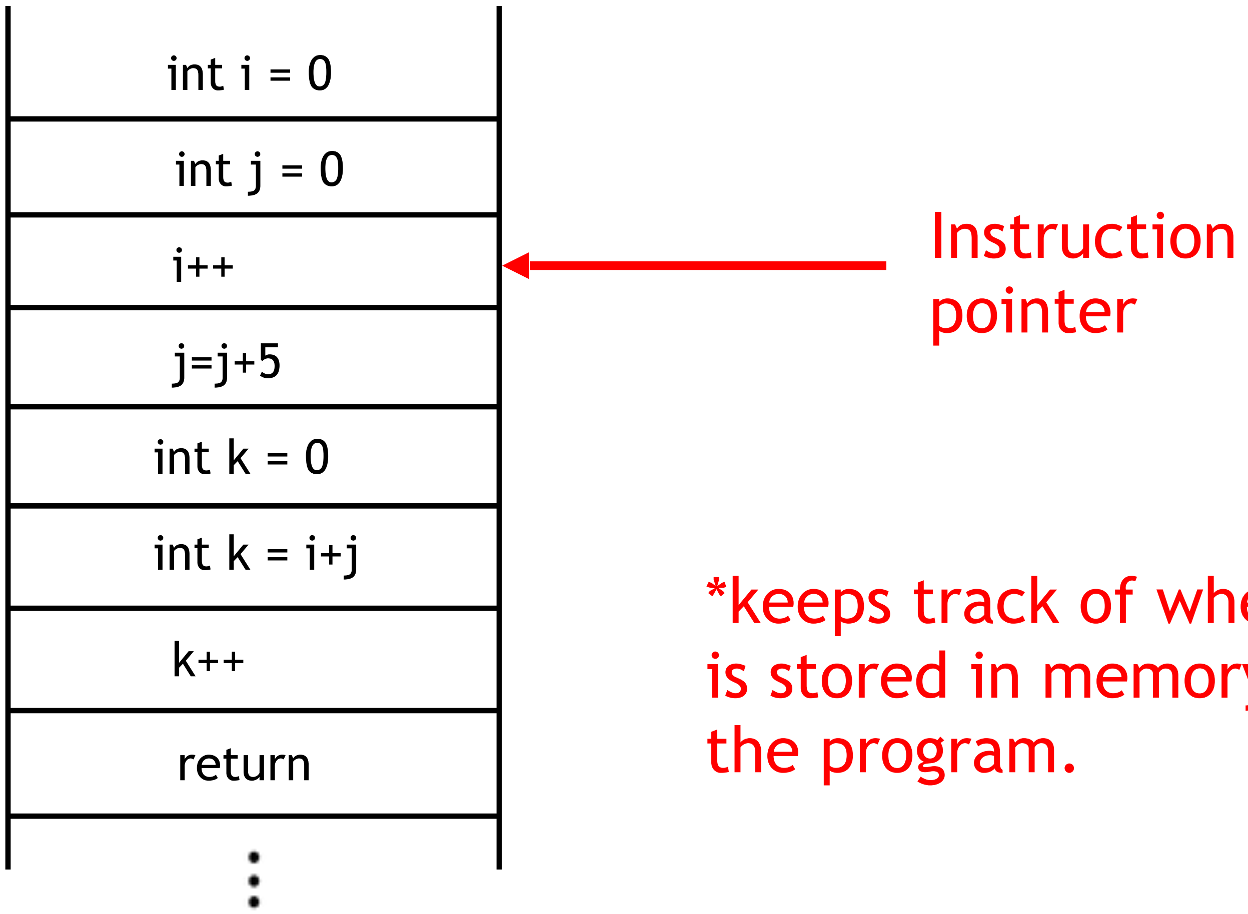
In reality:

Data



Code

The Instruction Pointer



*keeps track of where next instruction is stored in memory. Controls the flow of the program.

Proposed Defense: Good Fences Make Good Neighbors

Idea: W XOR X

- dedicated, fixed memory portions for writing data versus executable code.

Limitation 1: this approach doesn't make much sense in some contexts, e.g. websites where people have come to expect the flexibility of some kinds of executable code from untrusted sources.

Limitation 2: the implicit assumption underlying this defense is often false

On Quoting Out of Context…

Implicit Assumption => Explicit Attack Strategy

Undeniable Truth: Bad code can lead to bad behavior. This is why code injection attacks are scary.

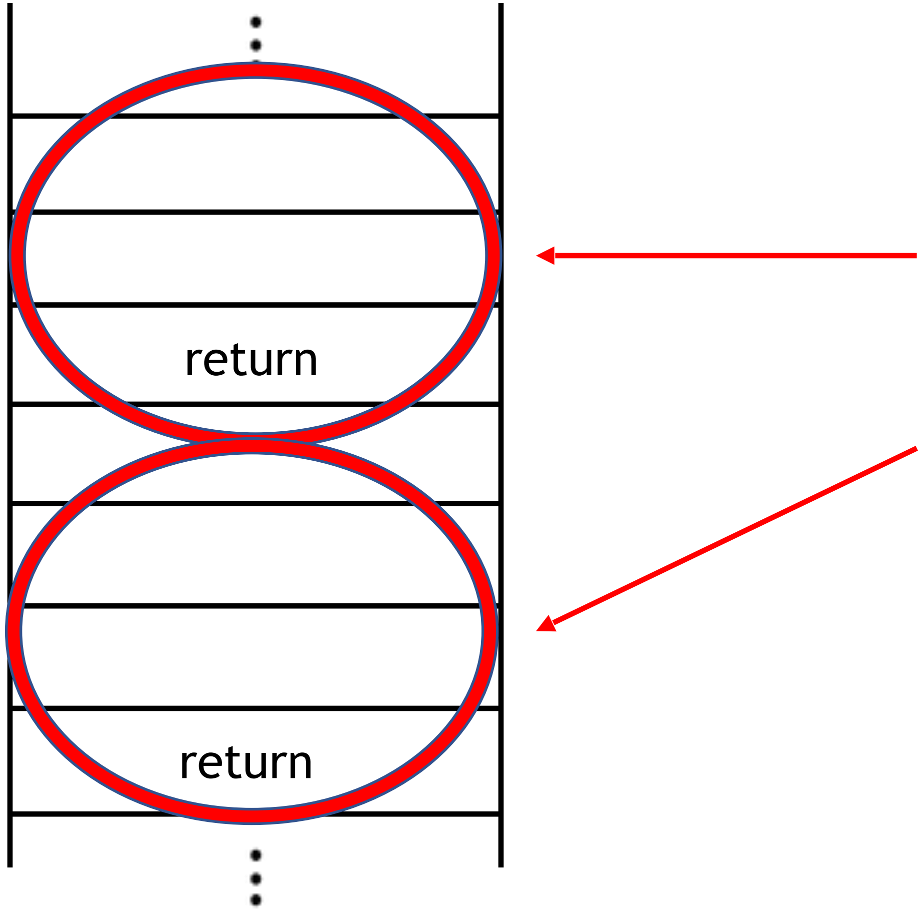
(False) Converse: Bad behavior is the result of bad co

Human analogy: Regular people can be manipulated into doing bad things.

Return-Oriented Programming [S07,BRSS08]

- Idea is to exploit snippets of legitimate code to achieve an unintended outcome
- Can be done successfully when control flow is subverted, no code injection necessary
- In retrospect, unsurprising that executing “good” code in an incorrect order can have “bad” consequences.

Return-Oriented Programming



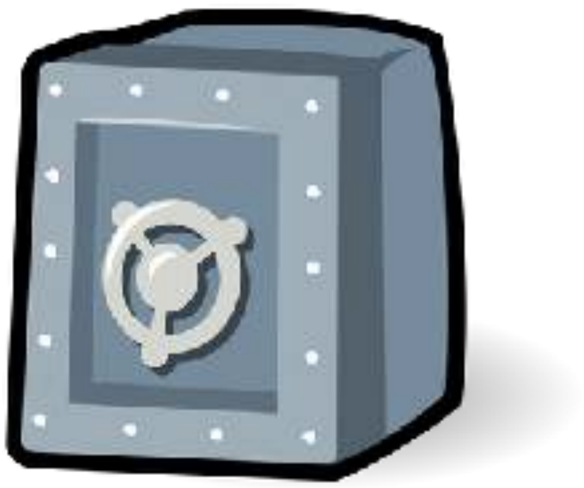
Gadgets of code
that end with “return”:
- Can be strung together
or malicious effects

On Surveillance …

Side-Channel Attacks on Cryptography

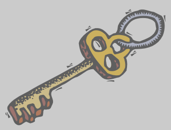
[K96,KJJ97,BS97,BB05, … and many more]

In our imaginations:



In reality:

Proposed Defense: Leakage-Resilient Cryptography [CDHKS00,ISW03,MR04, … and many many more]



Secret key

Attacker

Allow attacker to learn some limited information about the secret key

Try to prove security still holds

Leakage-Resilient Cryptography

Example guarantee:

- design algorithms for public key encryption so we can prove that:
  even if attacker learns 100 bits of information about a 1000-bit secret key,
  the desired security properties still hold!

- drawbacks: very difficult to decide if enough to capture real side-channel attack

the changes to the algorithms that allow us to prove this
might even exacerbate side channel attacks!

Meltdown and Spectre [LSGPHMKGYH17,KGGHHLMPSY17]

Speculative execution:

```
If (access allowed)
  read memory
Else
  ⋮
```

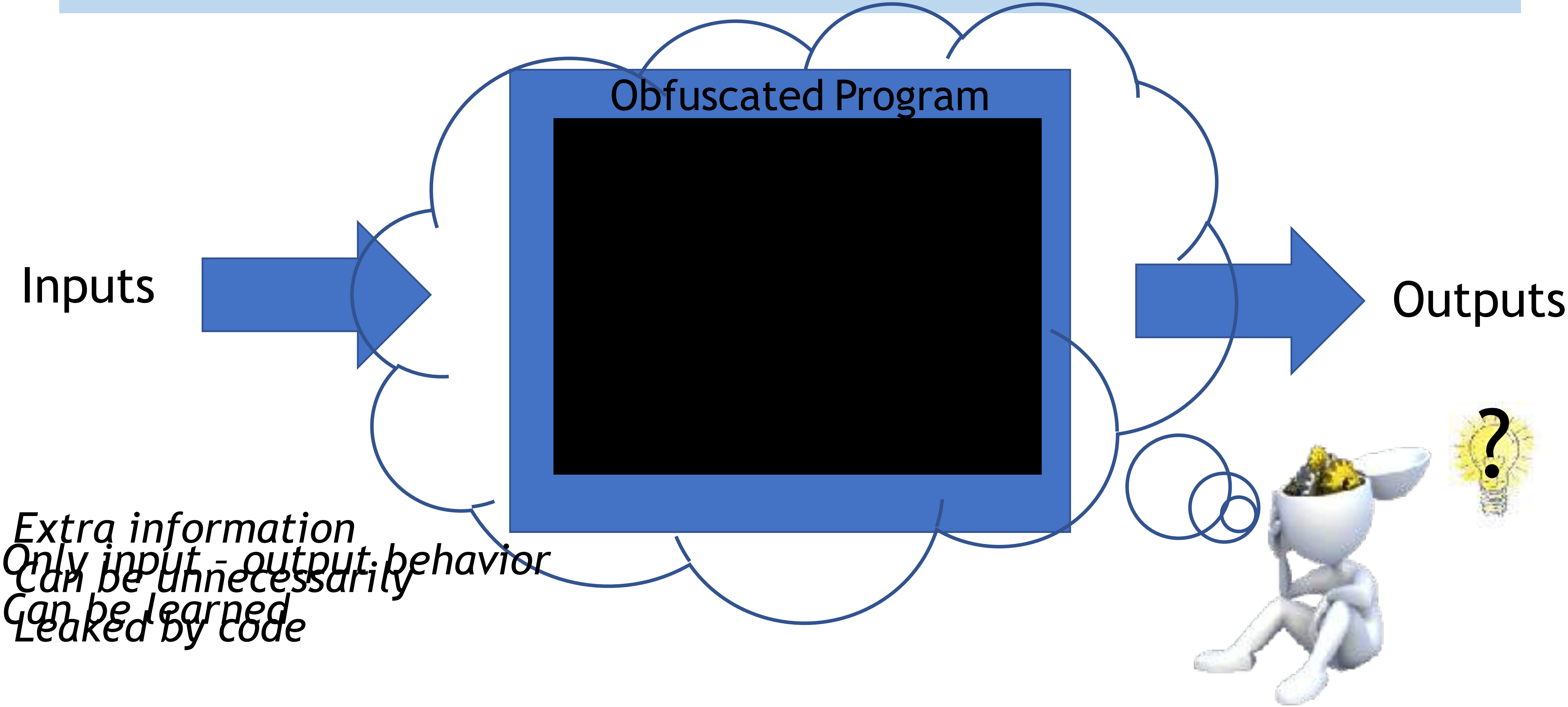
Later instructions may start
Executing ahead to save time

Effects will ”revert” for branche
Not taken

Some effects may linger – like what is stored in caches!

This may render access checks
Ineffective!

A Nuclear Option: Program Obfuscation
[BGIRSVY01, … and many many more]



Extra information
Only input - output behavior
Can be unnecessarily
Can be learned
Leaked by code

Possible Application: Software Patchi

Distributing security-critical update to many users:

Hmm… so that’s where the vulnerability was.

Patch itself may reveal an exploit that can be carried out on yet-to-be patched machines!

Obfuscation has the potential to fix this, and so much more!

A Paradigm Shift?

How we test algorithms today

How we will test algorithms tomorrow

Principles of Threat Modeling for Algorithms?

- Articulate clear, specific, narrow security goals
- Modular design: achieve high level security properties as a consequence of low level security prope
- Identify assumptions
- Test the viability of assumptions
- Model what happens when assumptions are violated:

Do modest violations of assumptions lead to modest or extreme violations of the security properties?

Adversarial Condition Simulations

A new regime for testing code?

Expand testing of correctness with differing inputs to testing of security properties in differing environments:

- Shared hardware
- Adversarial inputs
- Speculative execution
- …