Are We Ready For Secure Languages?

Cristina Cifuentes
Chief Galah
Oracle Labs Australia
July 2016

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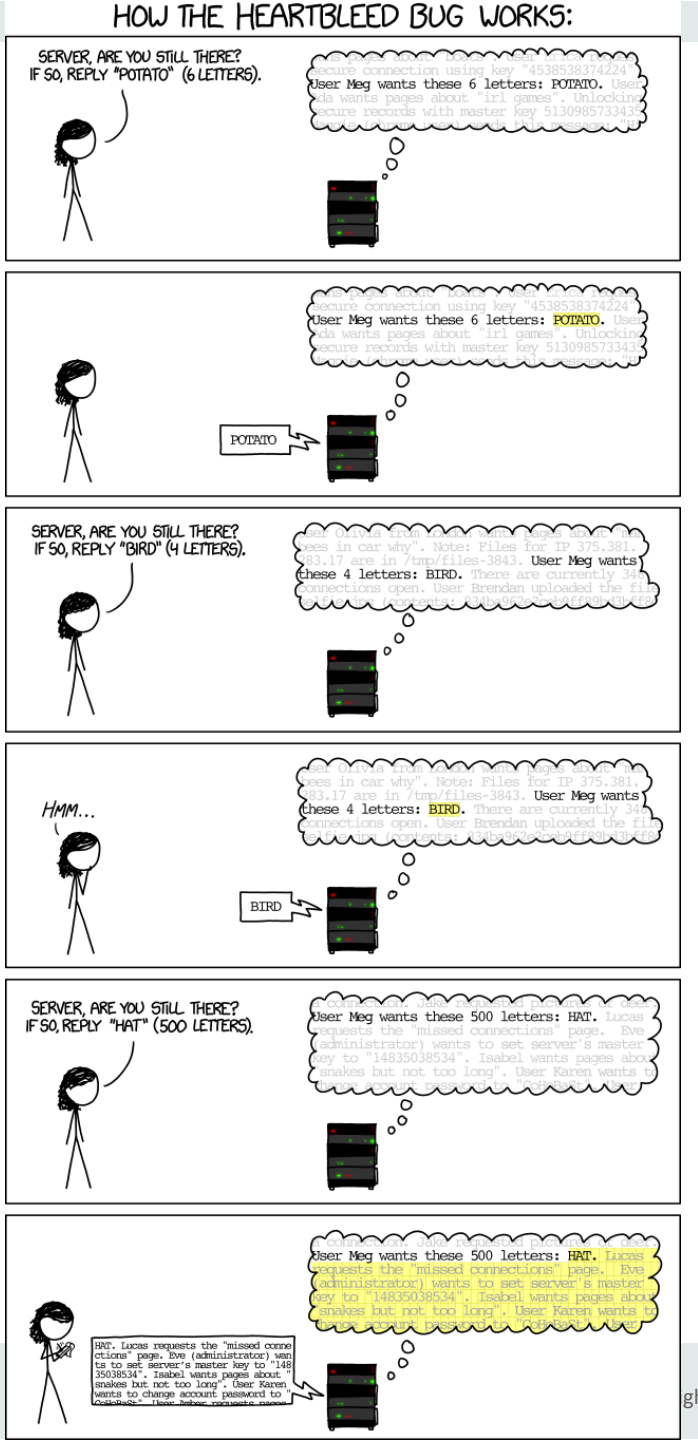

https://xkcd.com/1354/

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Buffer errors

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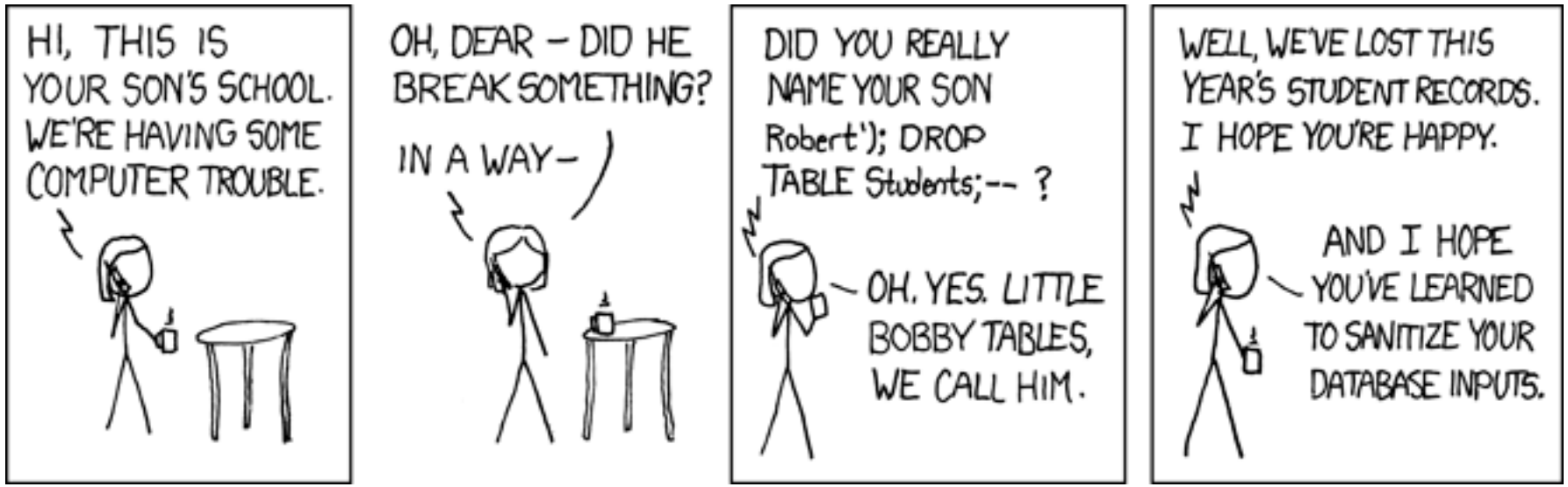

https://xkcd.com/327/

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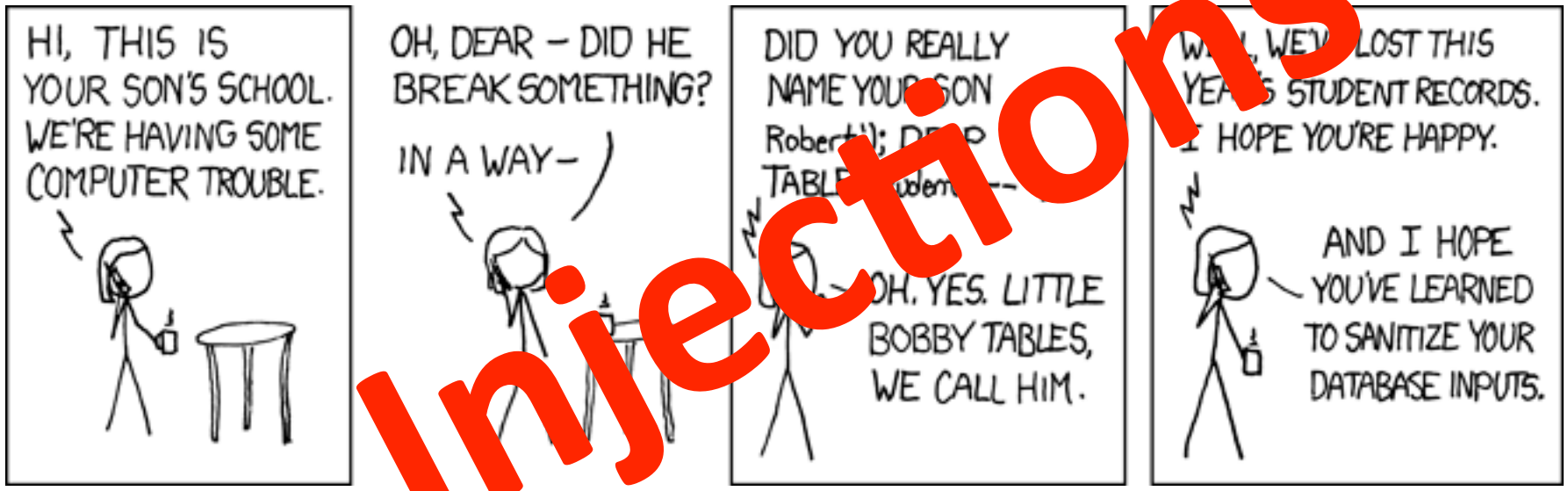

Injections

https://xkcd.com/327/

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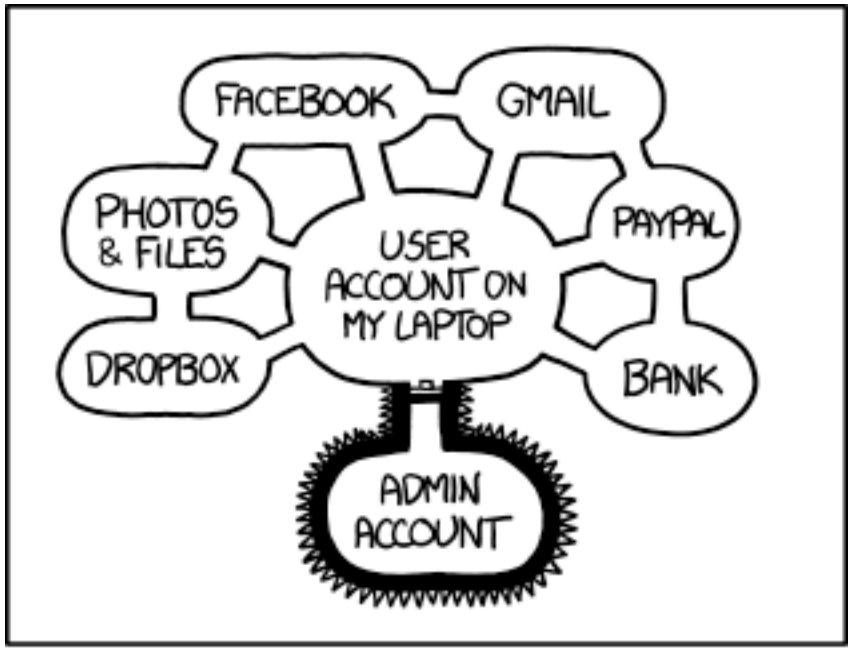

IF SOMEONE STEALS MY LAPTOP WHILE I'M LOGGED IN, THEY CAN READ MY EMAIL, TAKE MY MONEY, AND IMPERSONATE ME TO MY FRIENDS,

BUT AT LEAST THEY CAN'T INSTALL DRIVERS WITHOUT MY PERMISSION.

https://www.xkcd.com/1200/

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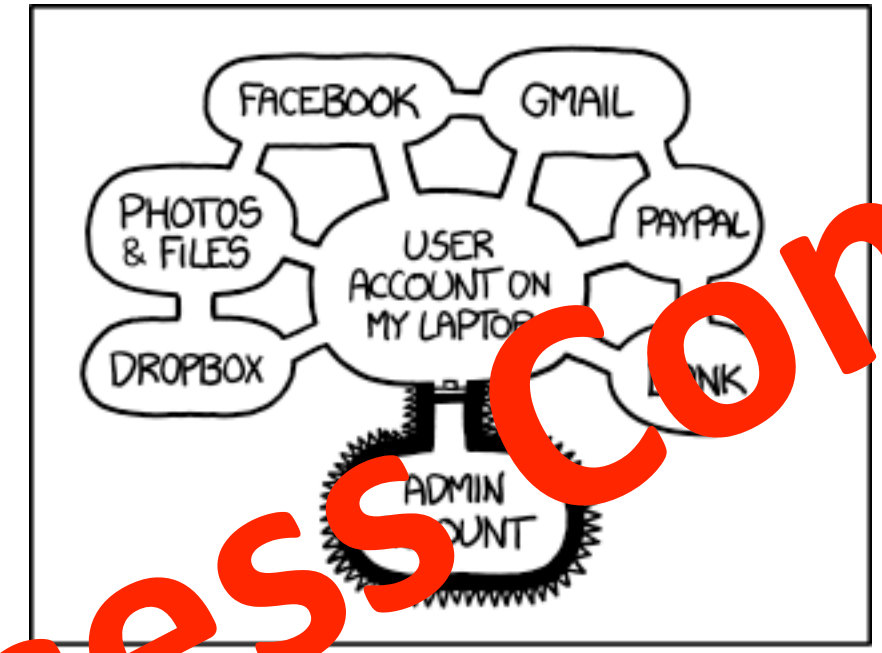

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Access Control

https://www.xkcd.com/1200/

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C, C++

Java
Java <-> C

Java EE
Java <-> C, Java <-> PL/SQL
JavaScript

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2477

Vulnerabilities due to **buffer errors** (2013-2015)

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2230

Vulnerabilities due to **cross-site scripting** (2013-2015)

National Vulnerability Database, http://nvd.nist.gov

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1793

Vulnerabilities due to **permissions, privileges and access control** (2013-2015)

National Vulnerability Database, http://nvd.nist.gov

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1972 Buffer overflow used in a kernel [1]

1988 Buffer overflow used in the Morris worm

1990s Cross-site scripting exploits

1998 SQL injection explained in the literature [2]

[1] Computer Security Technology Planning Study, 1972. [2] Phrack Magazine, 8(54), article 8

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How is this possible?

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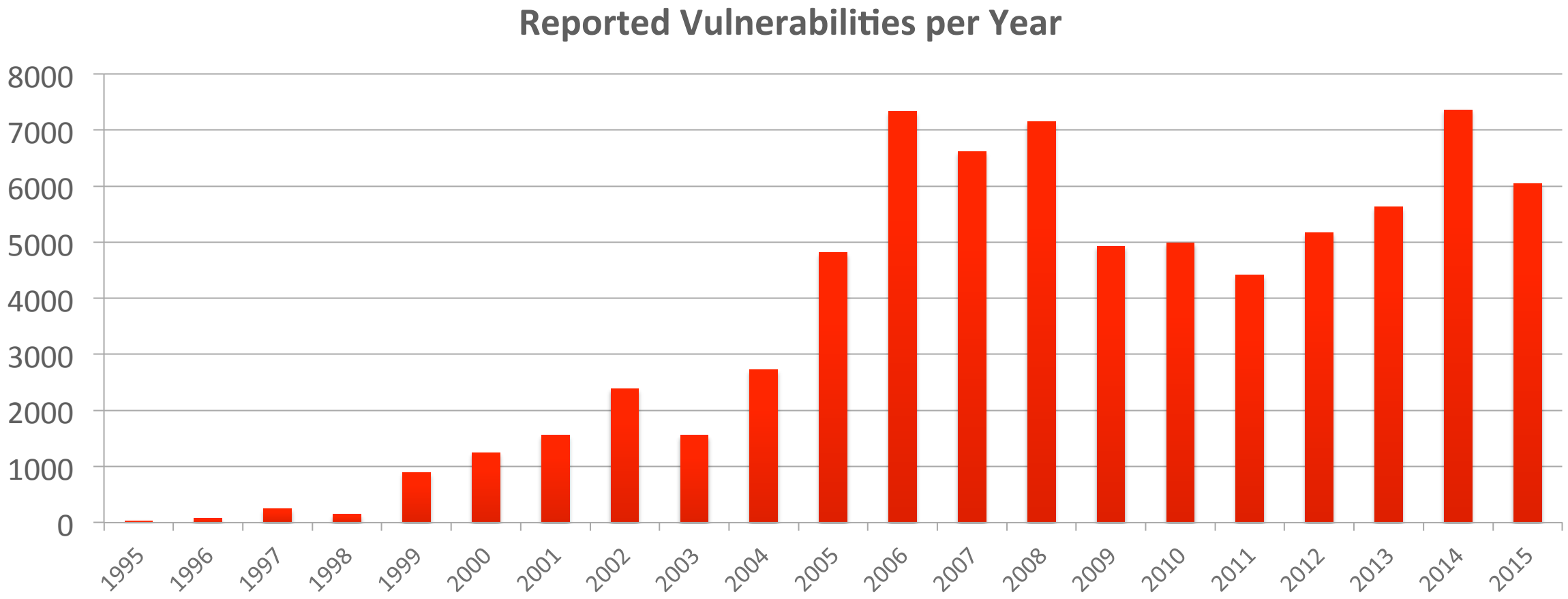

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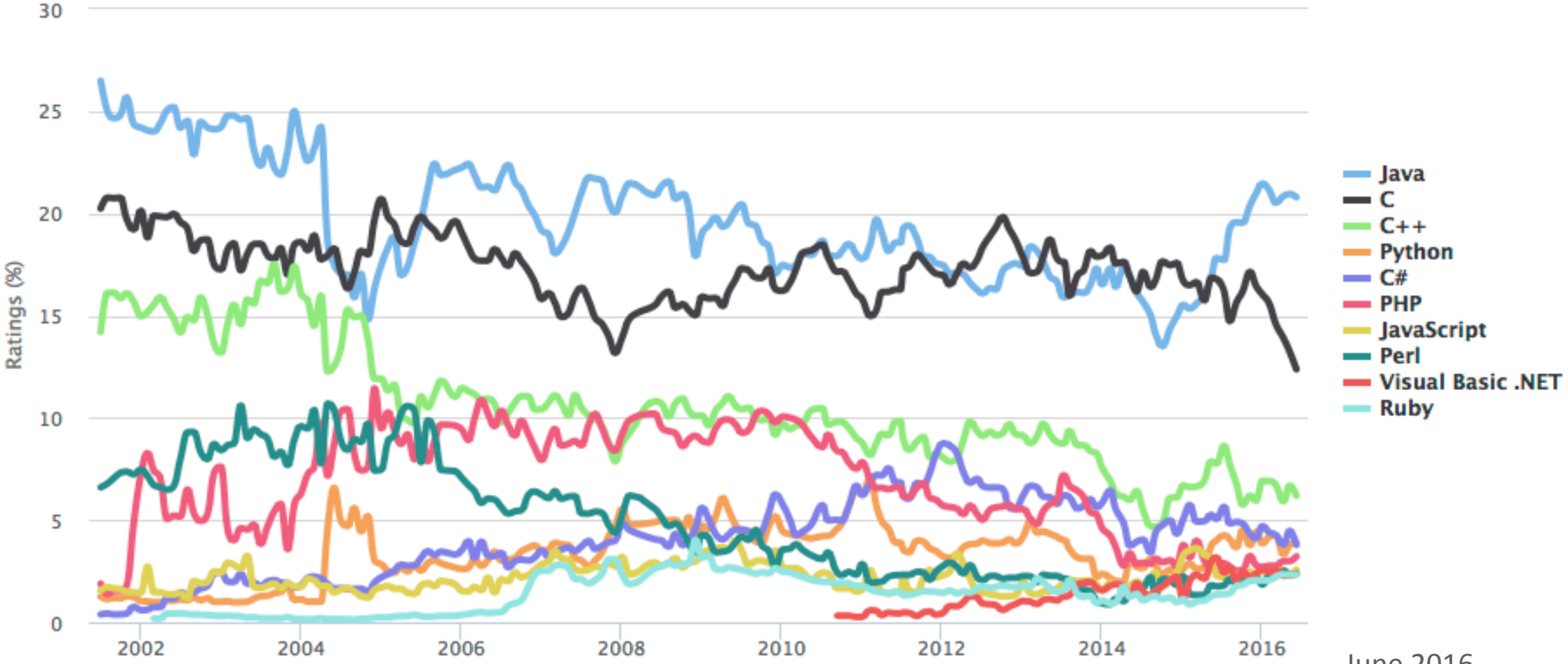
TIOBE Programming Community Index

Source: www.tiobe.com



June 2016

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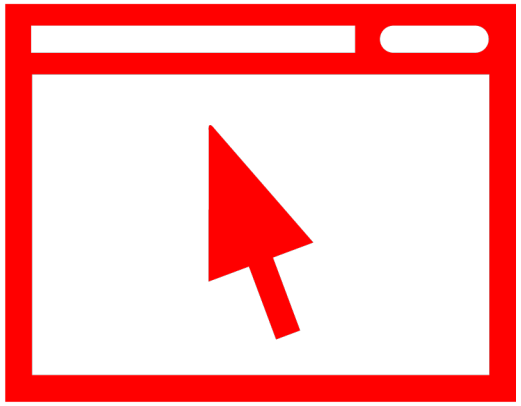

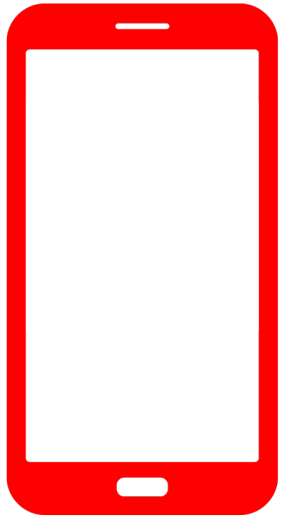

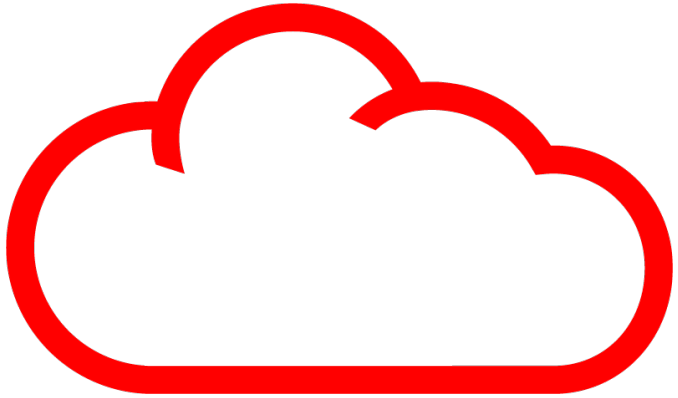

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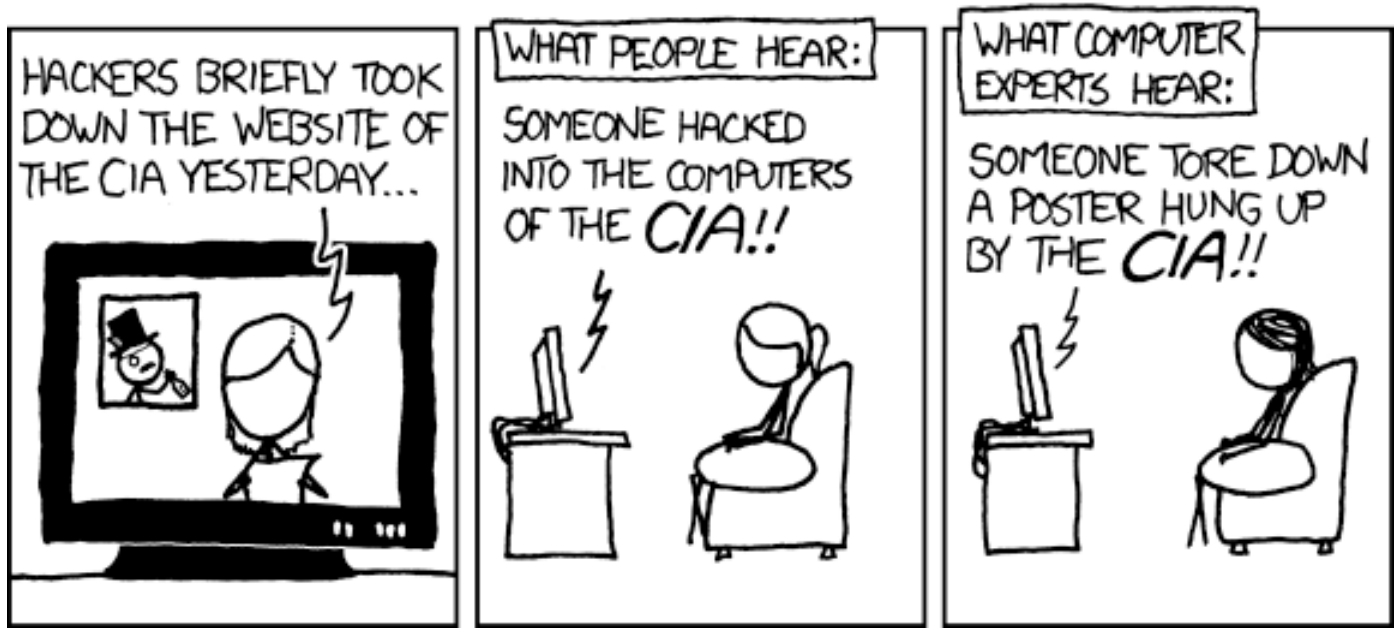

http://xkcd.com/932/

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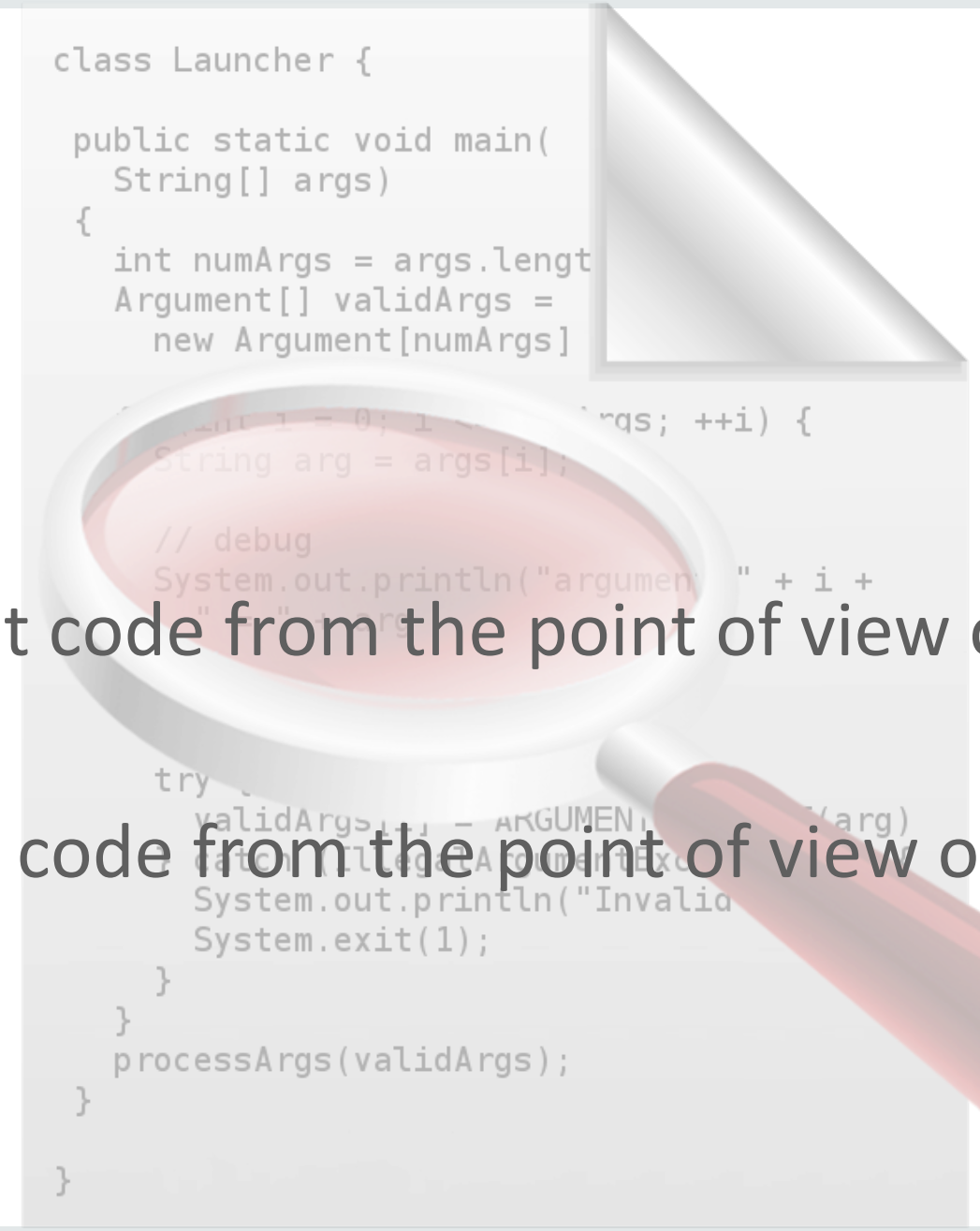

Attackers look at code from the point of view of how to **break** into it

Developers write code from the point of view of **functionality** required

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Sample Attacker Techniques

- **Buffer Errors**
  - Return to stack
  - RoP
  - Heap spray
  - Return to libc
  - …

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Sample Attacker Techniques

- **Buffer Errors**
  - Return to stack
  - RoP
  - Heap spray
  - Return to libc
  - …
- **Injections**
  - Missing validation altogether or validating SQL as HTML
  - Edge cases (e.g., partial sanitisation of HTML entities)
  - Use of blacklists rather than whitelists
  - …

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Sample Attacker Techniques

- **Buffer Errors**
  - Return to stack
  - RoP
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  - …
- **Injections**
  - Missing validation altogether or validating SQL as HTML
  - Edge cases (e.g., partial sanitisation of HTML entities)
  - Use of blacklists rather than whitelists
  - …
- **Access Control**
  - Missing checks
  - Incorrect checks (e.g., check for “logged in user” and not “logged in administrator”)

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Why Is This Happening?

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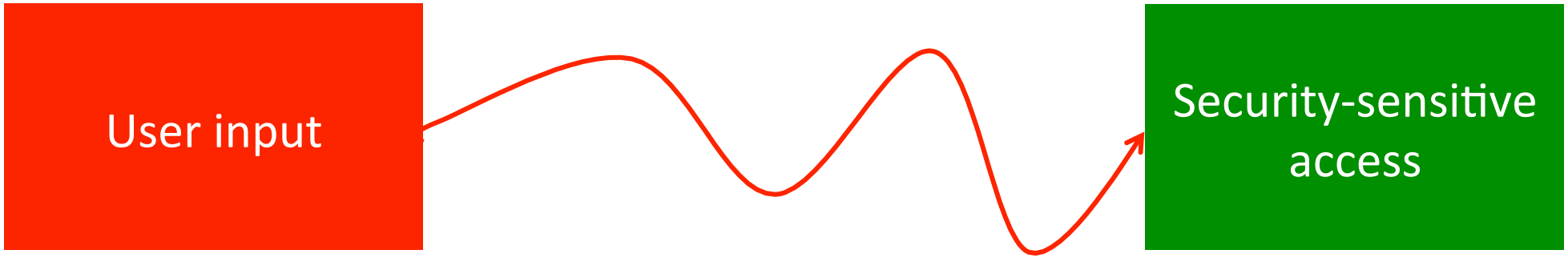
Buffer Errors
Injections
Access Control



data or code

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Need Sanitisation

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Sanitisation is the developer's responsibility

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Most languages do not provide sanitisation support

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Solution: Education

- Many PL subjects don’t cover security aspects per se
- Few universities offer PL Security courses at undergraduate level
- Companies do own training

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Solution: Education

- Many PL subjects don't cover security aspects per se
- Few universities offer PL Security courses at undergraduate level

Not Working

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Solution: Static Analysis Tools

- Re-parse the code with different compiler
- Encode semantics of PL in intermediate representation (IR)
- Analyse IR with over or under approximations
- Report bugs/vulnerabilities with False Positives (over) or False Negatives (under)

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Solution: Static Analysis Tools

- Re-parse the code with different compiler
- Encode semantics of PL in intermediate representation (IR)
- Analyse IR with over or under approximations
- Report bugs/vulnerabilities with False Positives (over) or False Negatives (under)

Incomplete

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Solutions: Dynamic and Verification Tools

Dynamic

- Dynamic analysis tools
  - Instrumentation
  - Introspection
- Fuzzing

Verification

- Model checking
- Theorem proving

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Solutions

Dynamic

- Dynamic analysis tools
  - Instrumentation
  - Introspection
- Fuzzing

Incomplete

Verification

- Model checking
- Theorem proving

Doesn't scale

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We can design languages that avoid some of these issues statically

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Avoid Buffer Errors Statically

Graydon Hoare, 2009

- Guaranteed memory safety
  - Ownership
  - Borrowing
    shared borrow (`&T`)
    mutable borrow (`&mut T`)
- Efficiency
  - Zero-cost abstractions
  - Parallelisation

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We can design languages or extensions that track some of these issues dynamically

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Avoid Buffer Errors Statically and Dynamically

- Extends C with bounds checking
  - 3 new checked pointer types: `ptr`, `array_ptr`, `span`
  - Bounds-checked arrays: `checked`
  - Checked member bounds
  - Bounds-safe interfaces
  - Checked program scopes
  - Lightweight invariants
  - Runtime errors on pointer arithmetic overflow and null pointer for `array_ptr`
- Dynamic checks

David Tarditi, June 2016 (v 0.5)

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Avoid Buffer Errors Dynamically

John McCarthy, 1958

- Managed memory
  - Garbage collection
  - First introduced in LISP in 1958
- Now in
  - OO languages: Smalltalk, Java, C#, JavaScript, Go
  - Functional languages: ML, Haskell, APL
  - Dynamic languages: Ruby, Perl, PHP

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Avoid Injections Dynamically

Larry Wall, 1987

- Taint mode
  - Perl 3, 1989
  - Automatic checks when program running with different real and effective user or group IDs
  - -T flag to turn it on
- Similar ideas in
  - Ruby

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We have made first steps to provide developers with access control support in the language

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First Steps at Avoiding Access Control Issues

James Gosling, 1991

- Safely run untrusted applets on your computer
- Security model
  - Java 1.2, 1998 [Li Gong]
  - Subscribes to the principle of least privilege
  - Security Manager mediates all access control decisions
  - Stack-based checks
- Similar ideas in
  - .NET framework

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Avoid Access Control Issues

Mark Miller, ~2010

- Extends/limits JavaScript to safely embed untrusted active content inside your web browser
  - Available as a plugin, ~2011
- Object-oriented capabilities
  - A capability-secure JS subset (SES – Secure ECMAScript)
  - A safe DOM wrapper (Domado)
  - A HTML and CSS sanitiser

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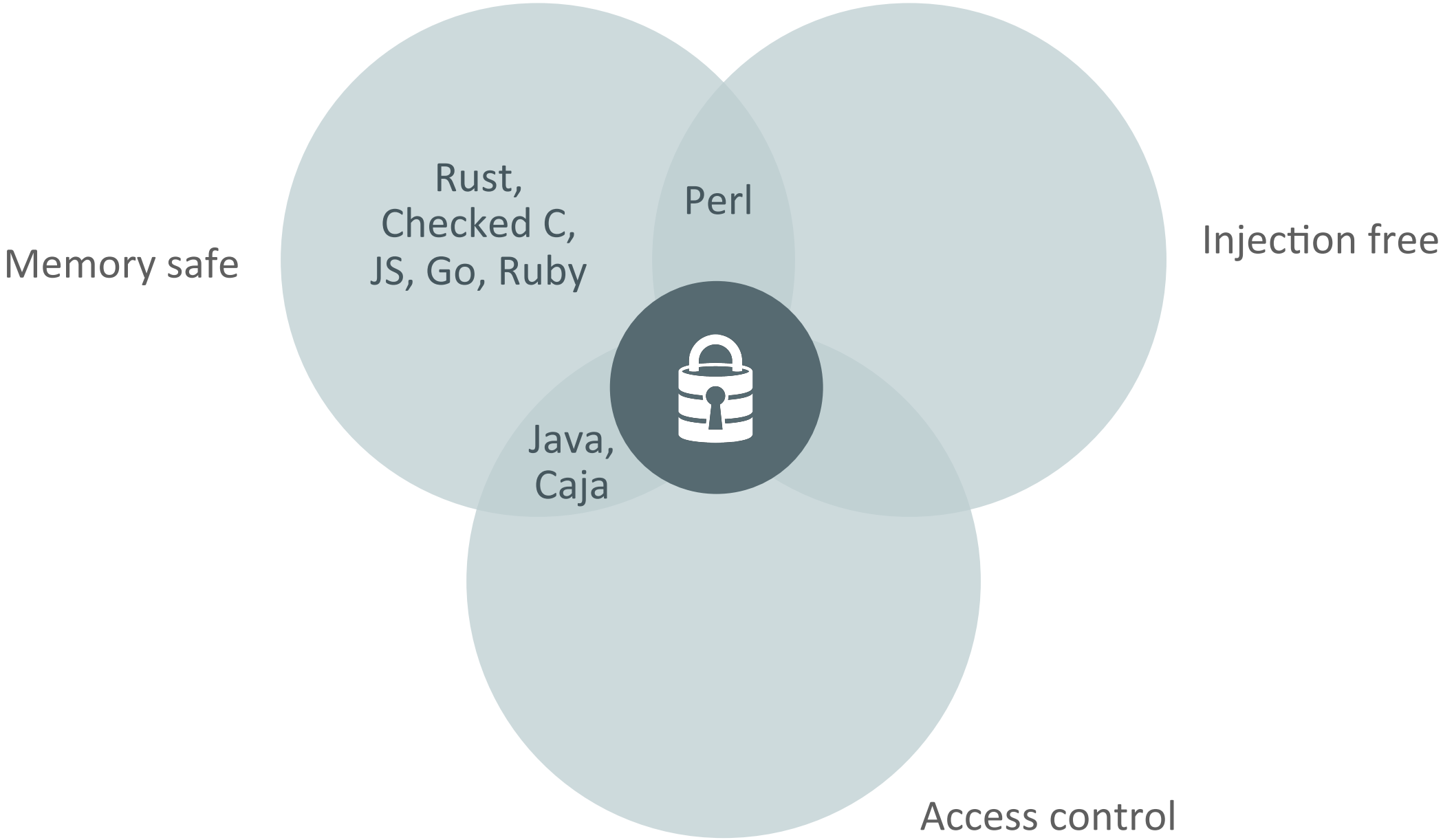

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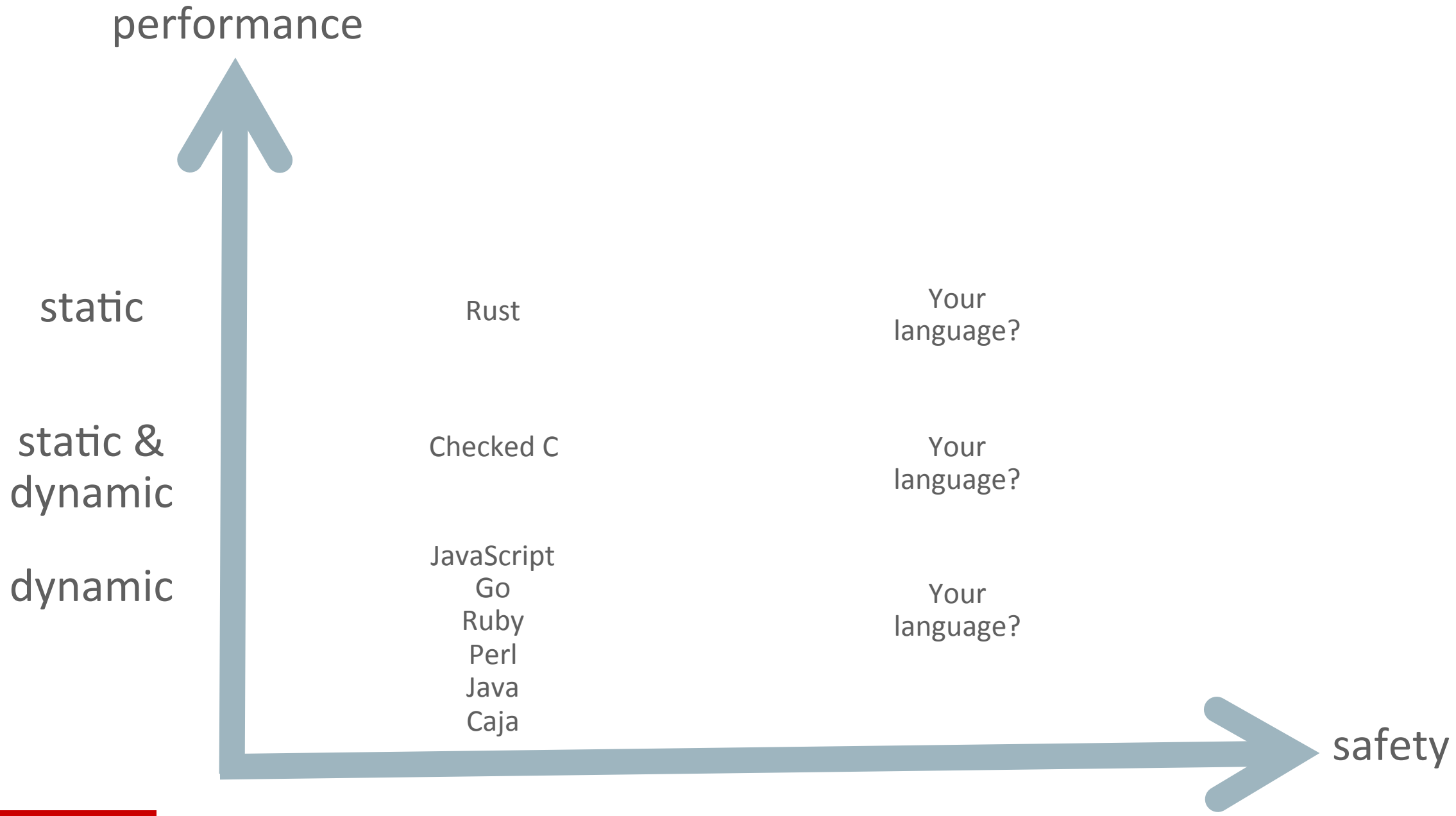

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Intermezzo

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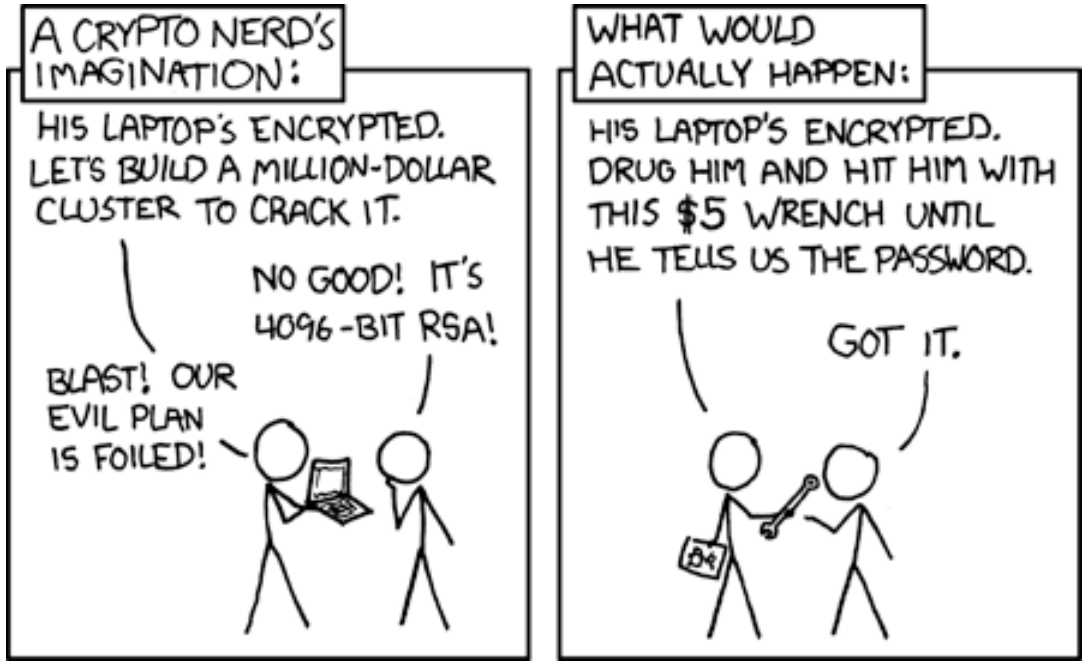

http://xkcd.com/538/

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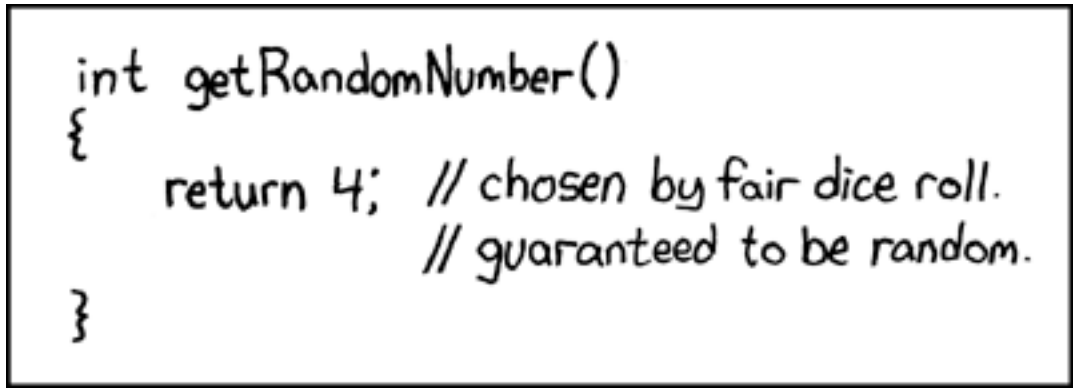

http://xkcd.com/221/

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1769

Vulnerabilities due to **cryptographic issues** (2013-2015)

National Vulnerability Database, http://nvd.nist.gov

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Cryptographic Issues

- Use of hardcoded passwords
- Use of deprecated algorithms
- Use of wrong defaults
- Use of hardcoded seeds
- Improperly hashed passwords
- Deterministic seeds to generate random numbers
- Valid users and host security keys left on an image of a cloud platform
- …

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Sample Attacker Techniques

- Poor API design (e.g., weak defaults)
- Weaknesses in protocols
- Use of deprecated suites
- “Breakthroughs”

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We have made first steps at providing a Cryptographic API for non-crypto developers to use

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First Steps to Avoid Cryptographic Issues

James Gosling, 1991

- Cryptography Architecture
  - Java 1.1, 1997
  - Framework for cryptography
  - APIs for encryption, key generation & management, secure random number generation, certificate validation, …
- Similar ideas in
  - .NET framework
  - PyCrypto
  - krypt for Ruby
  - crypto for Go, …

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Crypto APIs are too low level

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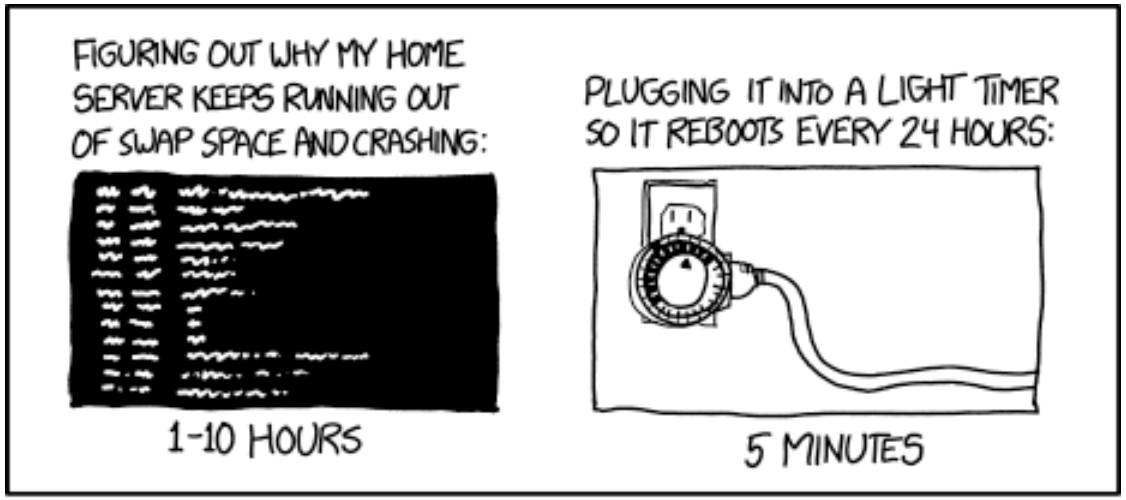

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894

Vulnerabilities due to **resource management** issues (2013-2015)

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Resource Management Issues

- Use after free
- Double free
- Memory corruption
- Type casting error
- Worker termination error

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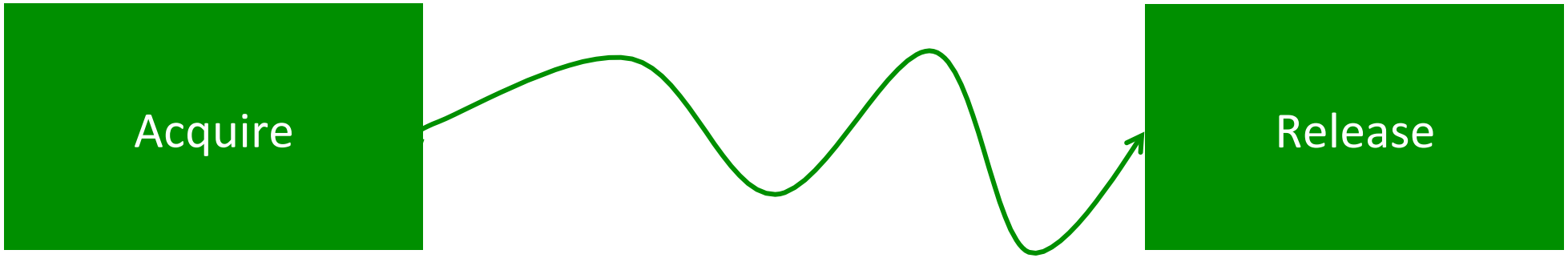
Resource Management Issues



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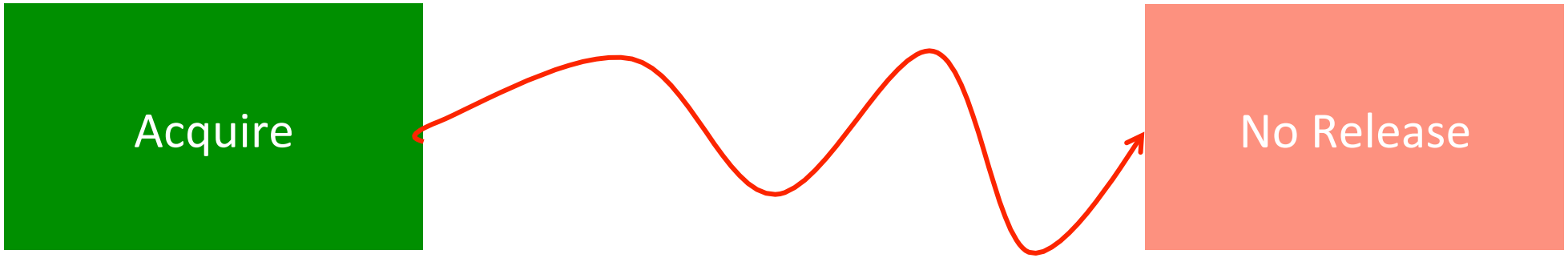
Resource Management Issues



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Few solutions to resource management issues are available

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Memory Safe languages avoid use-after-free and double-free issues

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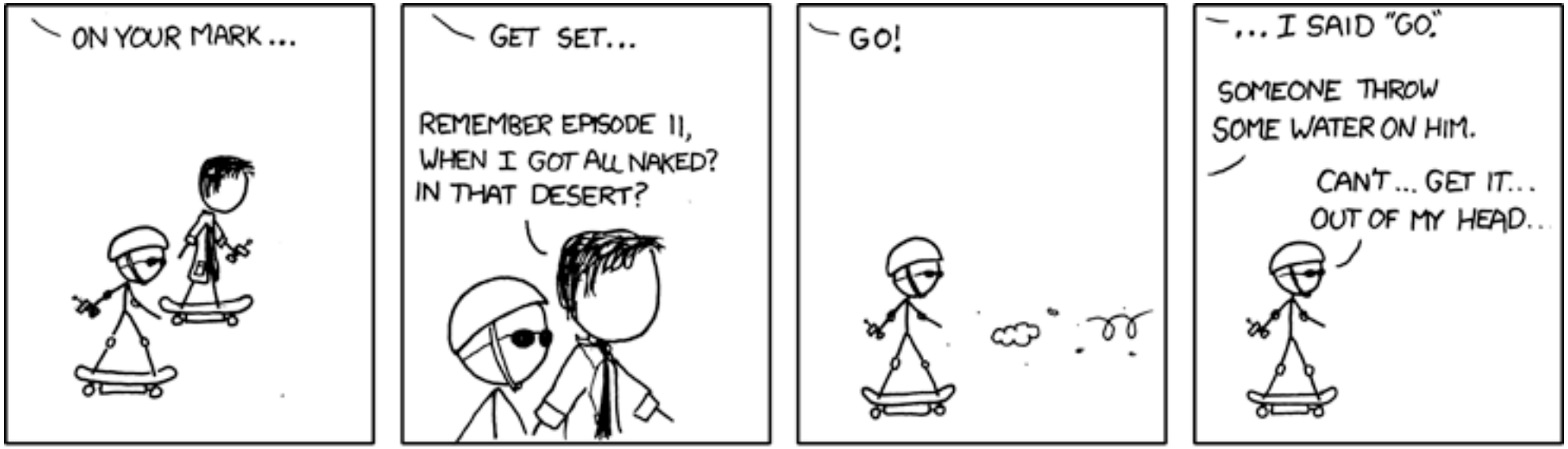

http://xkcd.com/580/

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149

Vulnerabilities due to **race conditions** (2013-2015)

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We need to consider the future concurrent world and make race conditions a thing of the past

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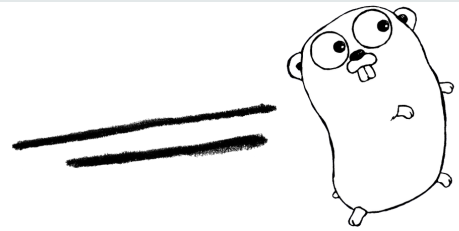
Concurrency by Default



- Goroutines for concurrency
  - CSP-style, light-weight process
  - `go`routines communicate and synchronise using `chan`nels
- Main goals
  - simplicity, safety and readability
- Not data-race free

Robert Griesemer, Rob Pike and Ken Thompson, 2007

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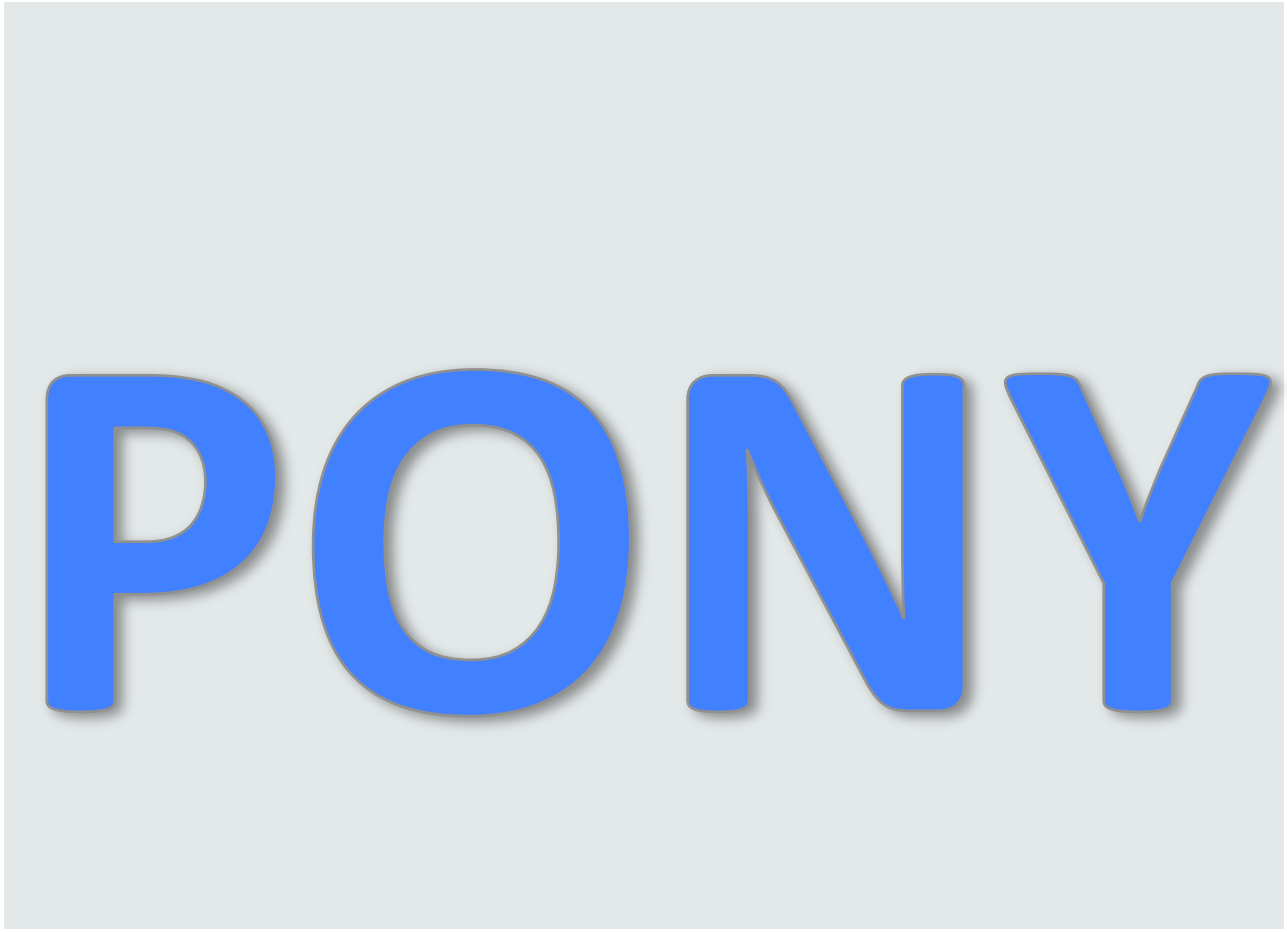
Avoid Race Conditions



Sylvan Clebsch, Sebastian Blessing, Sophia Drossopoulou, ~2014

- Actors for concurrency
  - Fast: zero-copy messaging
  - Safe: **data-race free type system**
- Reference capabilities/Type qualifiers based on deny properties
  - iso, trn, ref, val, box, tag

  attached to the path to an object
  - mutable, immutable, opaque

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Avoid Race Conditions

- Concurrency via immutable data structures
  - Identities: a series of immutable states over time

  and mutable reference types
- Designed for simplicity and data orientation

Rick Hickey, ~2005

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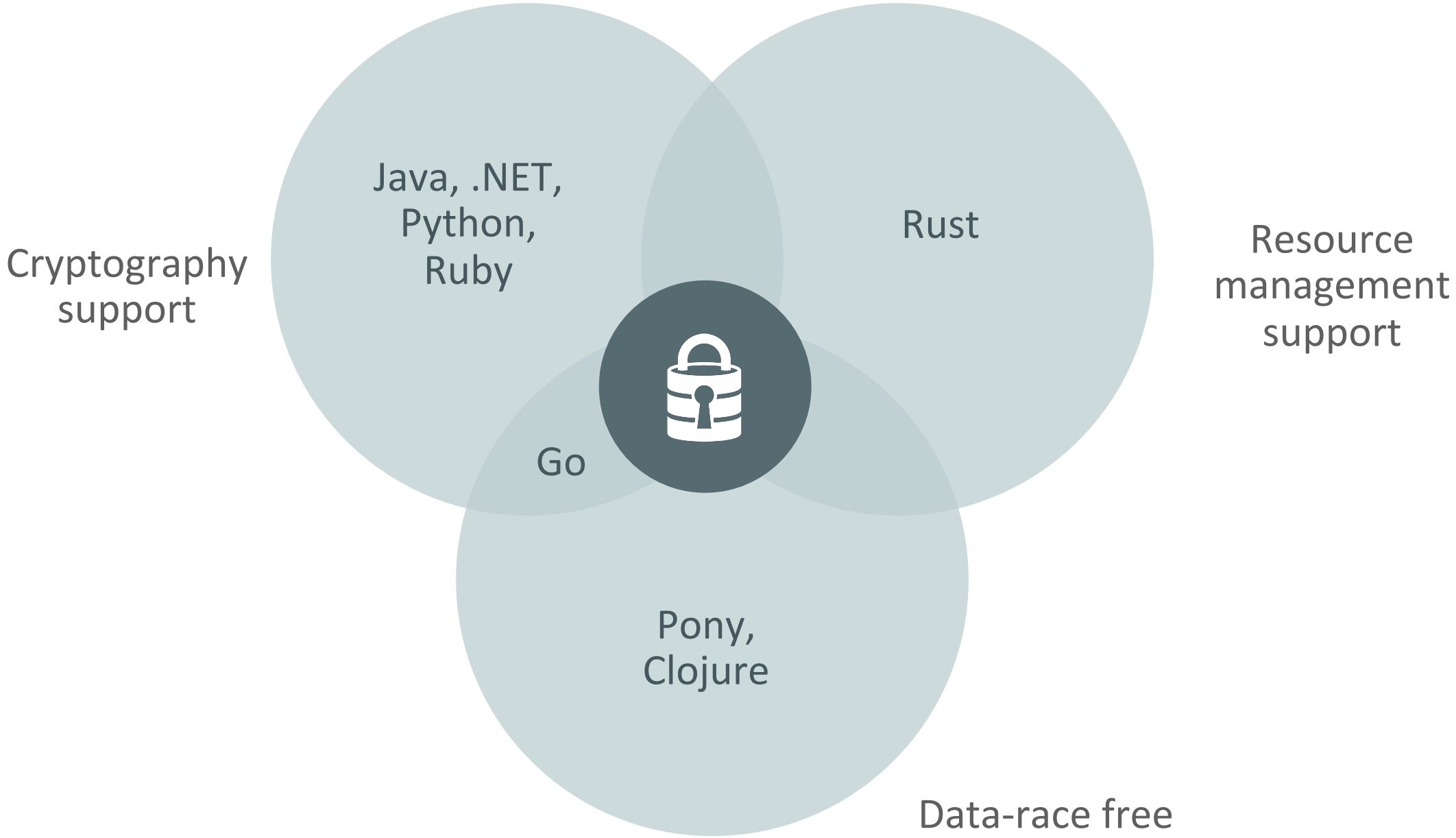

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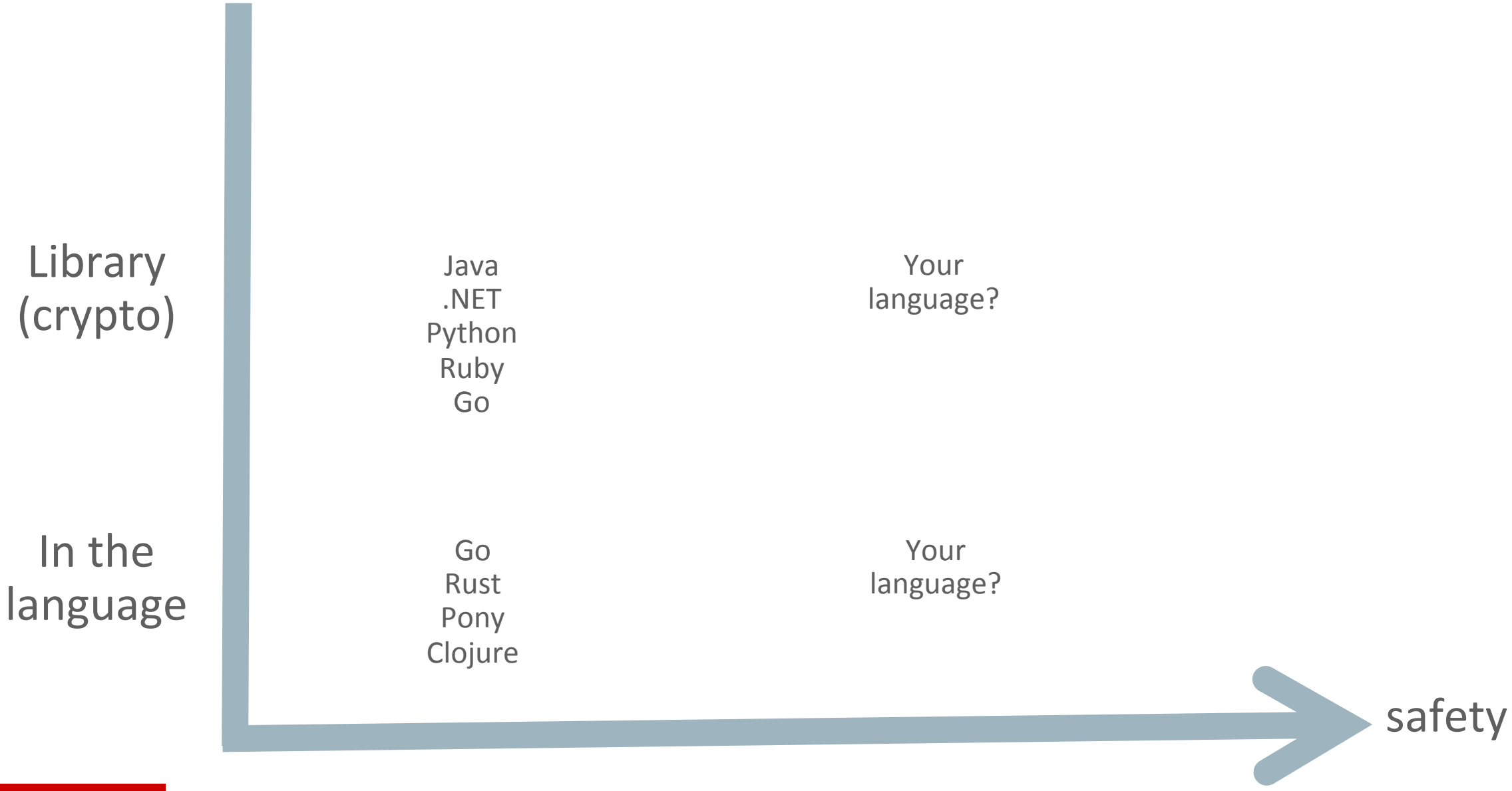

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What is Security in the Context of Programming Languages?

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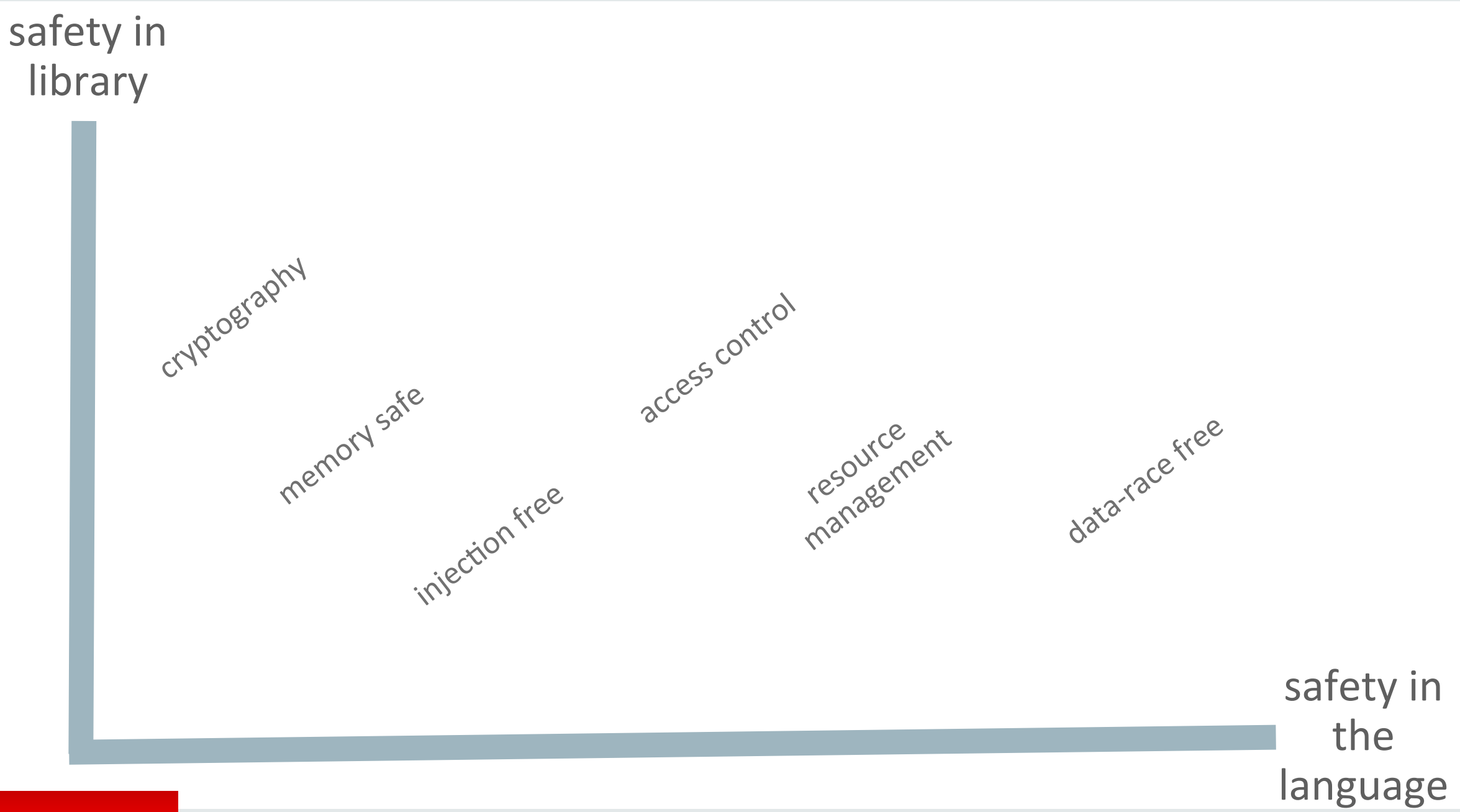

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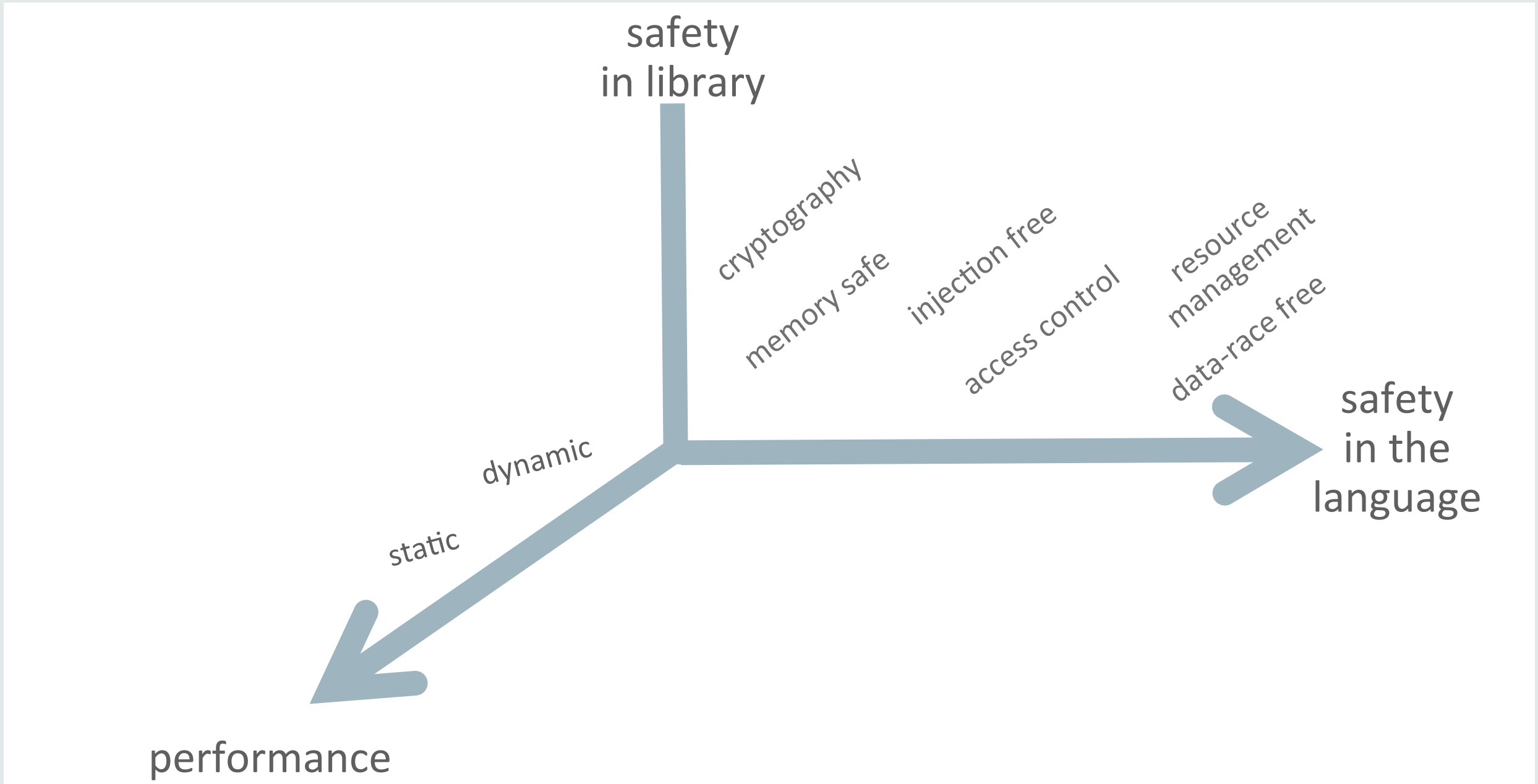

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Vulnerabilities in the past 3 years (2013-2015)

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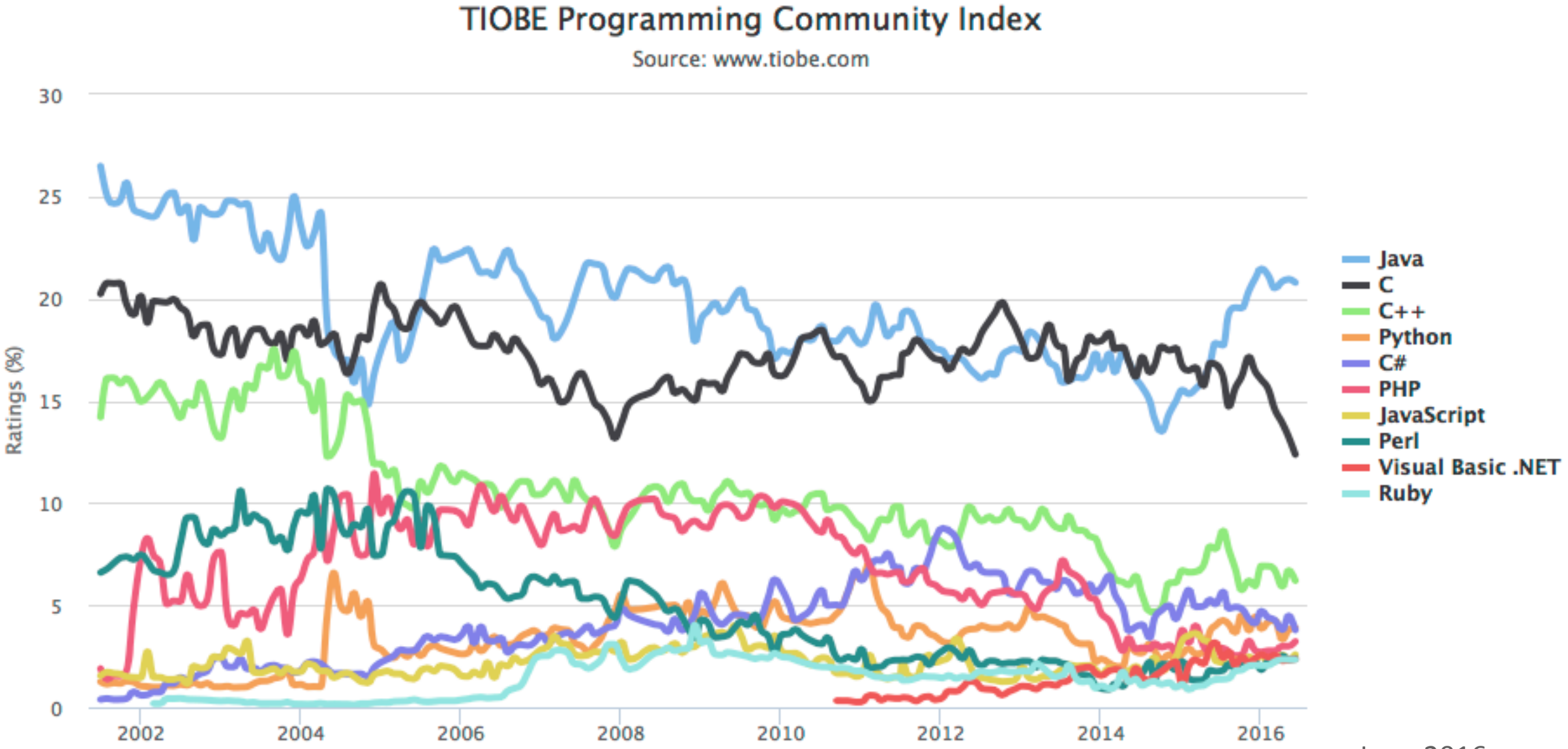

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Education lagging

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It’s time to include security in our language design

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There Will be Barriers for New Adoption

- Performance
- Usability
- Removing cognitive overload
- Legacy language support / interoperability / FFI

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Challenge – To design languages that provide security and eradicate buffer errors, injections, access control issues, cryptography issues, resource management issues and race conditions

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Challenge – To provide the context for tainted data that crosses along different layers

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Challenge – To provide high-level crypto APIs (e.g., stores password, does hashing) that don't require changes over time?

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Challenge – To provide security guarantees in the languages we design

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18.5

million software developers worldwide (11M professional, 7.5M hobbyist)

http://www.idc.com/research/viewtoc.jsp?containerId=244709, IDC December 2013 report

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Security in not just for expert developers

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We need security for the masses

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