Programming Languages

CS242

Lecture 1

Course Staff

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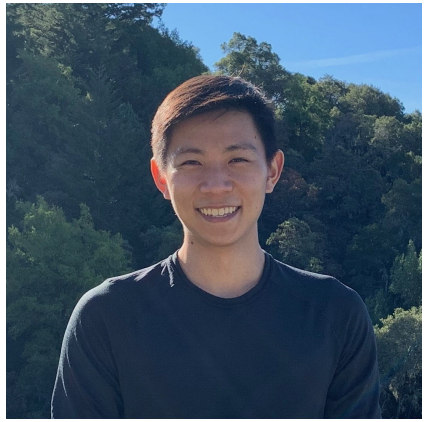


Jerry Chen

Xiaoyuan Ni

Important Info

See cs242.stanford.edu for other important course information

CS242: Programming Languages

- All things programming languages!
- Different families of programming languages
  - Including some you may have not seen before
  - In theory and practice
- Core ideas
  - Semantics
  - Type systems
  - Program analysis
  - Formal verification
- Core features
  - Continuations
  - Monads
  - Concurrency
  - Parallelism

Course Prerequisites

- Theory: CS 103
  - First-order logic, induction, discrete math
- Systems: CS 107 + 110
- Comfortable with programming
  - And learning new programming systems

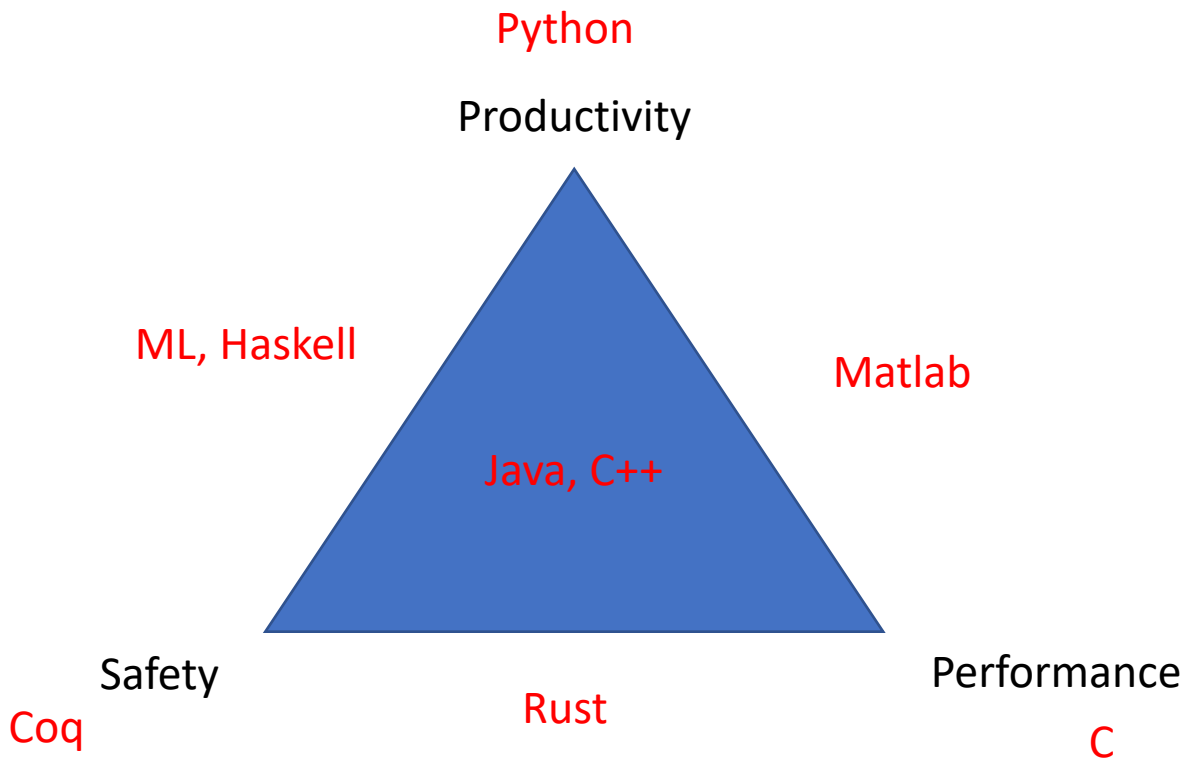
Course Structure

- Homeworks
  - 8 programming assignments
  - Roughly weekly, starting second week (56%)
  - Expect ~10 hours/week
- Readings
- Two exams
  - In-class midterm (19%)
  - Cumulative final (25%)

Takeaways

- Appreciation for programming languages as a technical field
  - The problems, the values, the “culture”
- Becoming a better programmer
  - Learn to think systematically about programming tools
- Understand the future
  - What we can do, what we can’t do, what we will likely be able to do
- Basics of active research areas
  - Preparation for research
- Thanks to Will Crichton for many of the slides in this lecture!

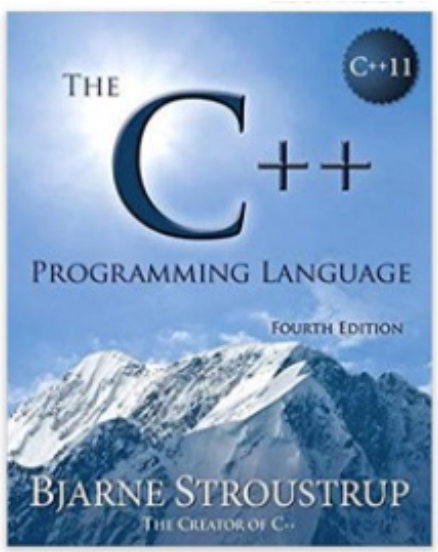
The Big Picture: Language Goals



Language Goals

- Every programming language has as goals
  - Performance
  - Productivity
  - Safety
- But there are tradeoffs
- And different designs make different choices
  - One of the reasons we have so many programming languages

Programming Languages are Complex Tools



Product details

Publisher : Addison-Wesley Professional; 4th edition (May

Language: : English

Paperback : 1376 pages

Item Weight : 2.73 pounds

Product details

Publisher : Wiley; 1st edition (July 8, 2014)

Language: : English

Paperback : 1152 pages

ISBN-10 : 1118907442

ISBN-13 : 978-1118907443

Item Weight : 6.04 pounds

Publisher : McGraw-Hill Education;

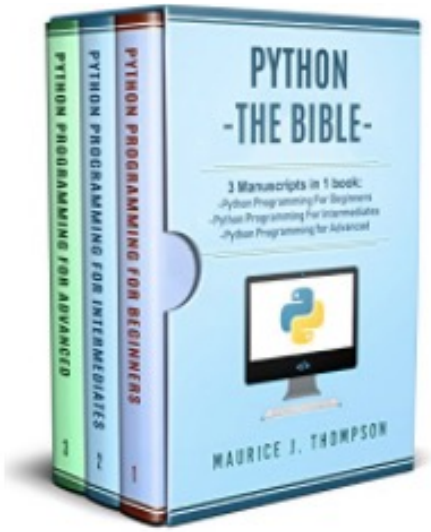
Language: : English

Paperback : 1248 pages

ISBN-10 : 1260440230

ISBN-13 : 978-1260440232

Item Weight : 3.86 pounds



Product details

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Text-to-Speech : Enabled

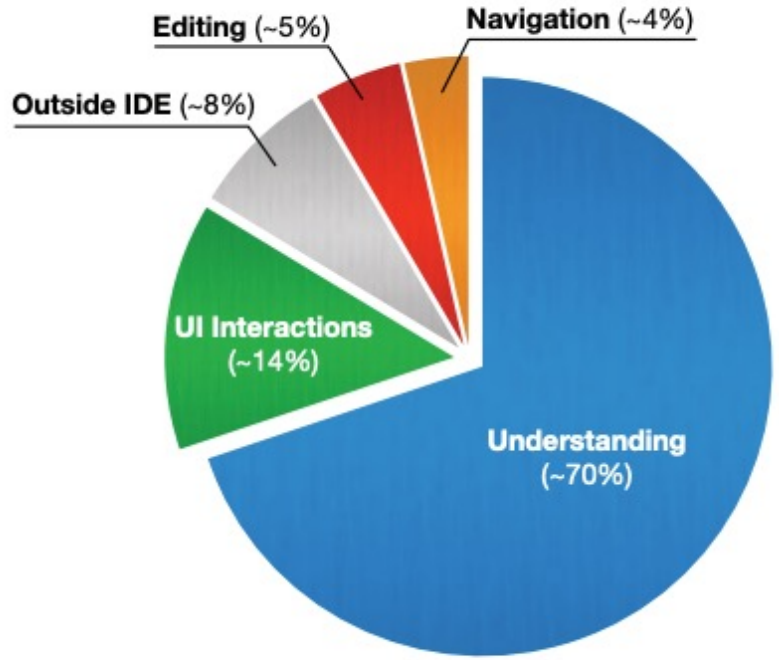
Enhanced typesetting : Enabled

X-Ray : Not Enabled

Word Wise : Not Enabled

Print length : 377 pages

Developers Are Reading, Not Writing

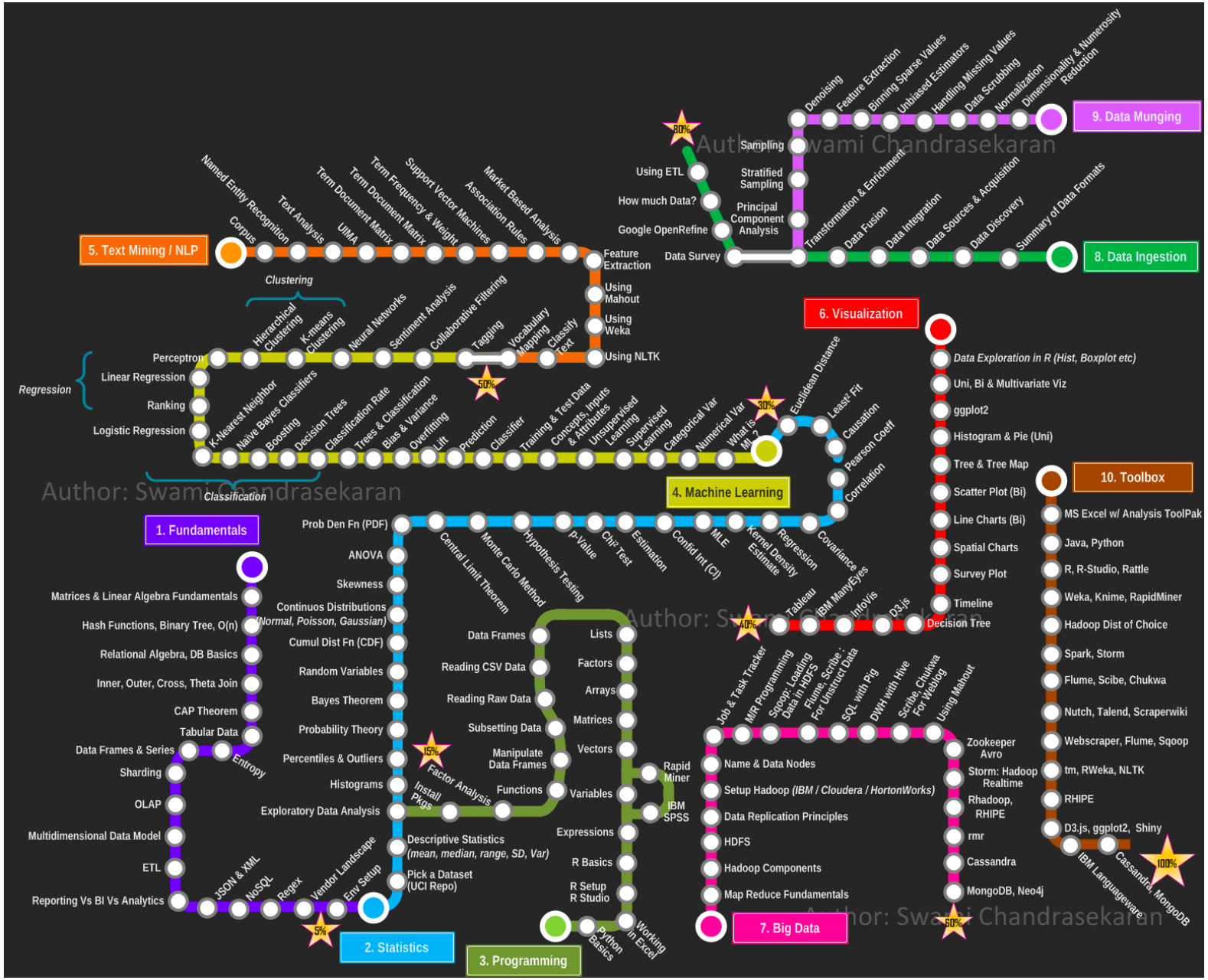


Minelli et al. “I Know What You Did Last Summer: An Investigation of How Developers Spend Their Time” ICPC ’15.

Project	Comprehension	Navigation	Editing	Others
Average	**57.62%**	**23.96%**	**5.02%**	**13.40%**

Xia et al. “Measuring Program Comprehension: A Large-Scale Field Study with Professionals.” IEEE Trans. Softw. Eng, 2018.

Complexity


5. Text Mining / NLP
Corpus
Named Entity Recognition
Text Analysis
UIMA
Term Document Matrix
Term Document Matrix
Term Frequency & Weight
Support Vector Machines
Association Rules
Market Based Analysis
Feature Extraction
Using Mahout
Using Weka
Using NLTK
Clustering
Hierarchical Clustering
K-means Clustering
Neural Networks
Sentiment Analysis
Collaborative Filtering
Tagging
Vocabulary Mapping
Classify Text
Regression
Perceptron
Linear Regression
Ranking
Logistic Regression
K-Nearest Neighbor
Naive Bayes Classifiers
Boosting
Decision Trees
Classification Rate
Trees & Classification
Bias & Variance
Overfitting
Lift
Prediction
Classifier
Training & Test Data
Concepts, Inputs & Attributes
Unsupervised Learning
Supervised Learning
Categorical Var
Numerical Var
What is ML?
Classification
50%
9. Data Munging
Denoising
Feature Extraction
Binning Sparse Values
Unbiased Estimators
Handling Missing Values
Data Scrubbing
Normalization
Dimensionality & Numerosity Reduction
80%
Sampling
Stratified Sampling
Principal Component Analysis
Using ETL
How much Data?
Google OpenRefine
Data Survey
8. Data Ingestion
Transformation & Enrichment
Data Fusion
Data Integration
Data Sources & Acquisition
Data Discovery
Summary of Data Formats
6. Visualization
Data Exploration in R (Hist, Boxplot etc)
Uni, Bi & Multivariate Viz
ggplot2
Histogram & Pie (Uni)
Tree & Tree Map
Scatter Plot (Bi)
Line Charts (Bi)
Spatial Charts
Survey Plot
Timeline
Decision Tree
40%
Tableau
IBM ManyEyes
InfoVis
D3.js
4. Machine Learning
30%
Euclidean Distance
Least² Fit
Causation
Pearson Coeff
Correlation
Author: Swami Chandrasekaran
10. Toolbox
MS Excel w/ Analysis ToolPak
Java, Python
R, R-Studio, Rattle
Weka, Knime, RapidMiner
Hadoop Dist of Choice
Spark, Storm
Flume, Scibe, Chukwa
Nutch, Talend, Scraperwiki
Webscraper, Flume, Sqoop
tm, RWeka, NLTK
RHIPE
D3.js, ggplot2, Shiny
IBM Languageware
Cassandra, MongoDB
100%
1. Fundamentals
Matrices & Linear Algebra Fundamentals
Hash Functions, Binary Tree, O(n)
Relational Algebra, DB Basics
Inner, Outer, Cross, Theta Join
CAP Theorem
Tabular Data
Data Frames & Series
Entropy
Sharding
OLAP
Multidimensional Data Model
ETL
Reporting Vs BI Vs Analytics
JSON & XML
NoSQL
Regex
Vendor Landscape
Env Setup
5%
Prob Den Fn (PDF)
ANOVA
Skewness
Continuos Distributions (Normal, Poisson, Gaussian)
Cumul Dist Fn (CDF)
Random Variables
Bayes Theorem
Probability Theory
Percentiles & Outliers
Histograms
Exploratory Data Analysis
Descriptive Statistics (mean, median, range, SD, Var)
Pick a Dataset (UCI Repo)
Central Limit Theorem
Monte Carlo Method
Hypothesis Testing
p-Value
Chi² Test
Estimation
Confid Int (CI)
MLE
Kernel Density Estimate
Regression
Covariance
15%
Factor Analysis
Install Pkgs
2. Statistics
Data Frames
Reading CSV Data
Reading Raw Data
Subsetting Data
Manipulate Data Frames
Functions
Lists
Factors
Arrays
Matrices
Vectors
Variables
Expressions
R Basics
R Setup R Studio
Rapid Miner
IBM SPSS
Python Basics
Working in Excel
3. Programming
Job & Task Tracker
MR Programming
Sqoop: Loading Data in HDFS
Flume, Scribe : For Unstruct Data
SQL with Pig
DWH with Hive
Scribe, Chukwa For Weblog
Using Mahout
Name & Data Nodes
Setup Hadoop (IBM / Cloudera / HortonWorks)
Data Replication Principles
HDFS
Hadoop Components
Map Reduce Fundamentals
Zookeeper Avro
Storm: Hadoop Realtime
Rhadoop, RHIPE
rmr
Cassandra
MongoDB, Neo4j
60%
7. Big Data

std::move_if_noexcept

Defined in header <utility>

```
template< class T >
typename std::conditional<
    !std::is_nothrow_move_constructible<T>::value && std::is_copy_constructible<T>::value,
    const T&,
    T&&
>::type move_if_noexcept(T& x) noexcept;
```
(since C++11) (until C++14)

```
template< class T >
constexpr typename std::conditional<
    !std::is_nothrow_move_constructible<T>::value && std::is_copy_constructible<T>::value,
    const T&,
    T&&
>::type move_if_noexcept(T& x) noexcept;
```
(since C++14)

`move_if_noexcept` obtains an rvalue reference to its argument if its move constructor does not throw exceptions or if there is no copy constructor (move-only type), otherwise obtains an lvalue reference to its argument. It is typically used to combine move semantics with strong exception guarantee.

Parameters

x - the object to be moved or copied

Return value

`std::move(x)` or `x`, depending on exception guarantees.

Notes

This is used, for example, by `std::vector::resize`, which may have to allocate new storage and then move or copy elements from old storage to new storage. If an exception occurs during this operation, `std::vector::resize` undoes everything it did to this point, which is only possible if `std::move_if_noexcept` was used to decide whether to use move construction or copy construction. (unless copy constructor is not available, in which case move constructor is used either way and the strong exception guarantee may be waived)

Example

Run this code

```
#include <iostream>
#include <utility>
```

6.7.3.1 Formal definition of `restrict`

1 Let **D** be a declaration of an ordinary identifier that provides a means of designating an object **P** as a restrict-qualified pointer to type **T**.

2 If **D** appears inside a block and does not have storage class **extern**, let **B** denote the block. If **D** appears in the list of parameter declarations of a function definition, let **B** denote the associated block. Otherwise, let **B** denote the block of **main** (or the block of whatever function is called at program startup in a freestanding environment).

3 In what follows, a pointer expression **E** is said to be *based* on object **P** if (at some sequence point in the execution of **B** prior to the evaluation of **E**) modifying **P** to point to a copy of the array object into which it formerly pointed would change the value of **E**.[119] Note that "based" is defined only for expressions with pointer types.

4 During each execution of **B**, let **L** be any lvalue that has **&L** based on **P**. If **L** is used to access the value of the object **X** that it designates, and **X** is also modified (by any means), then the following requirements apply: **T** shall not be const-qualified. Every other lvalue used to access the value of **X** shall also have its address based on **P**. Every access that modifies **X** shall be considered also to modify **P**, for the purposes of this subclause. If **P** is assigned the value of a pointer expression **E** that is based on another restricted pointer object **P2**, associated with block **B2**, then either the execution of **B2** shall begin before the execution of **B**, or the execution of **B2** shall end prior to the assignment. If these requirements are not met, then the behavior is undefined.

5 Here an execution of **B** means that portion of the execution of the program that would correspond to the lifetime of an object with scalar type and automatic storage duration

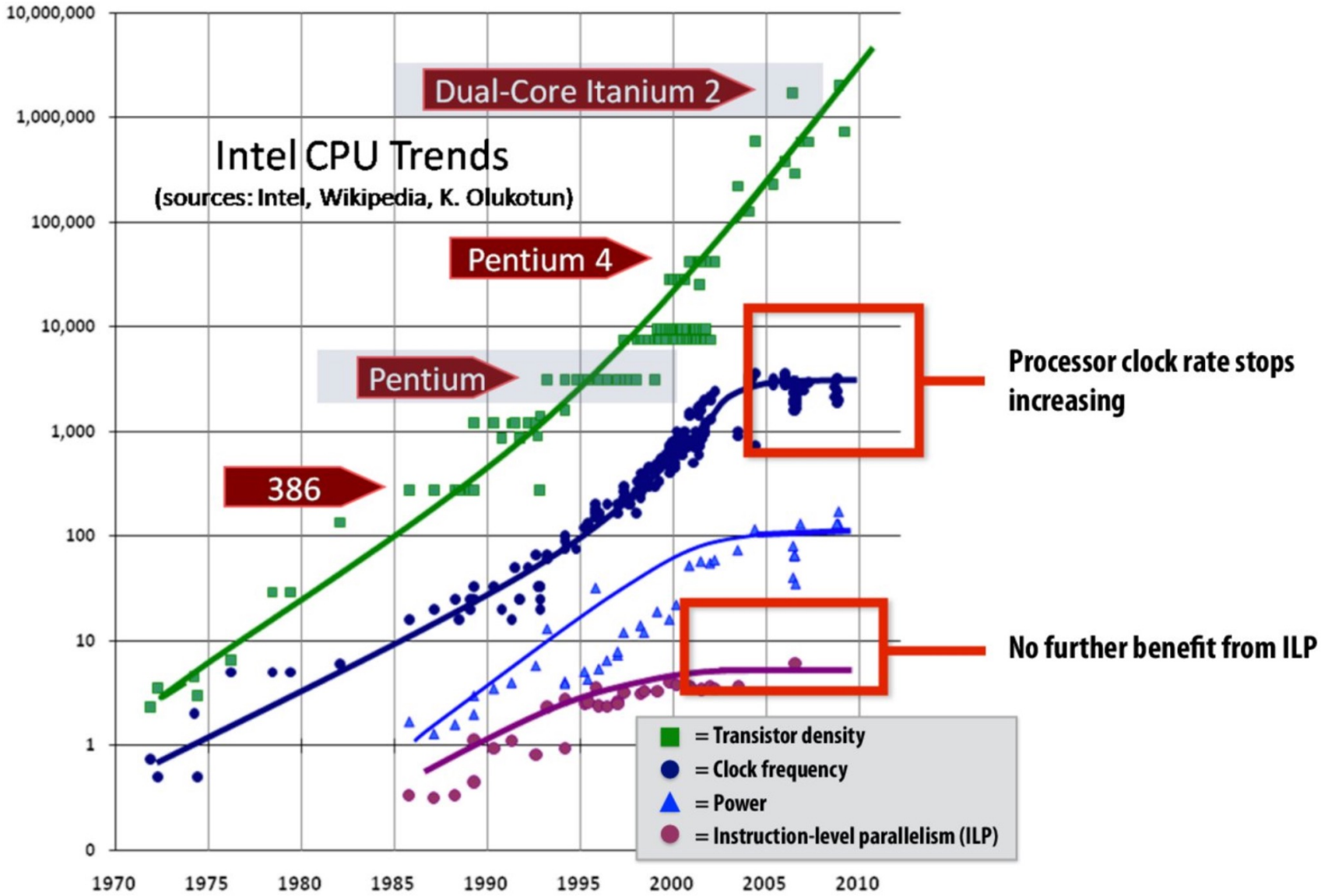


Image credit: "The free Lunch is Over" by Herb Sutter, Dr. Dobbs 2005

Memory usage continues to scale

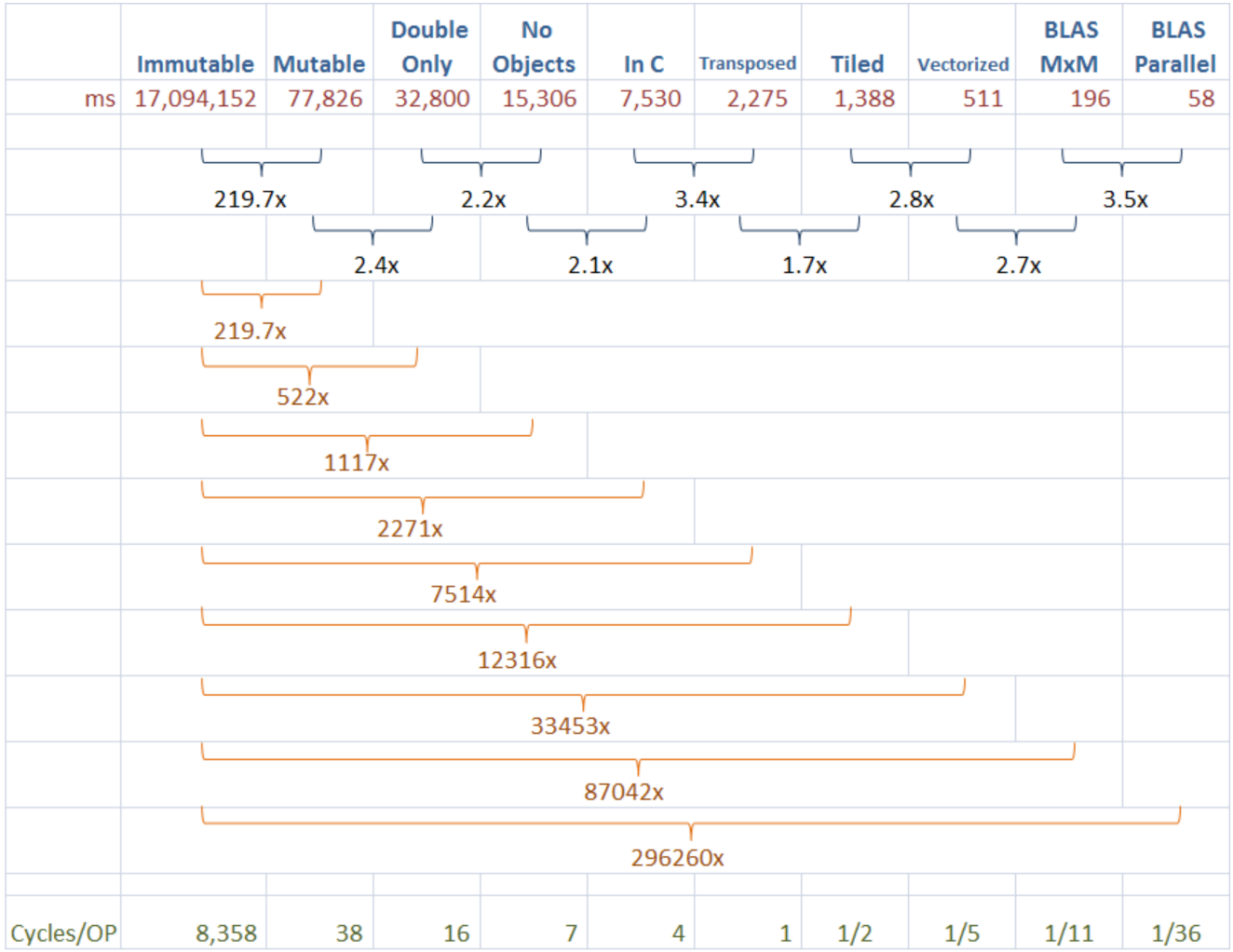
Process Name	Memory
Slack Helper	365.8 MB
Slack Helper	234.9 MB
Slack	91.8 MB
Slack Helper	89.8 MB

700 MB!

Process Name	Memory	Co
Google Chrome Helper	738.8 MB	
Google Chrome Helper	419.8 MB	
Google Chrome Helper	399.4 MB	
Google Chrome Helper	366.4 MB	
Google Chrome	317.8 MB	
Google Chrome Helper	57.2 MB	
Google Chrome Helper	54.9 MB	
Google Chrome Helper	53.5 MB	
Google Chrome Helper	45.2 MB	
Google Chrome Helper	44.5 MB	
Google Chrome Helper	44.0 MB	
Google Chrome Helper	43.8 MB	
Google Chrome Helper	43.6 MB	
Google Chrome Helper	43.5 MB	
Google Chrome Helper	43.3 MB	
Google Chrome Helper	43.2 MB	
Google Chrome Helper	43.1 MB	
Google Chrome Helper	42.8 MB	
Google Chrome Helper	40.0 MB	
Google Chrome Helper	30.1 MB	
Google Chrome Helper	18.8 MB	
Google Chrome Helper	18.4 MB	
Google Chrome Helper	17.3 MB	

3 GB!!!

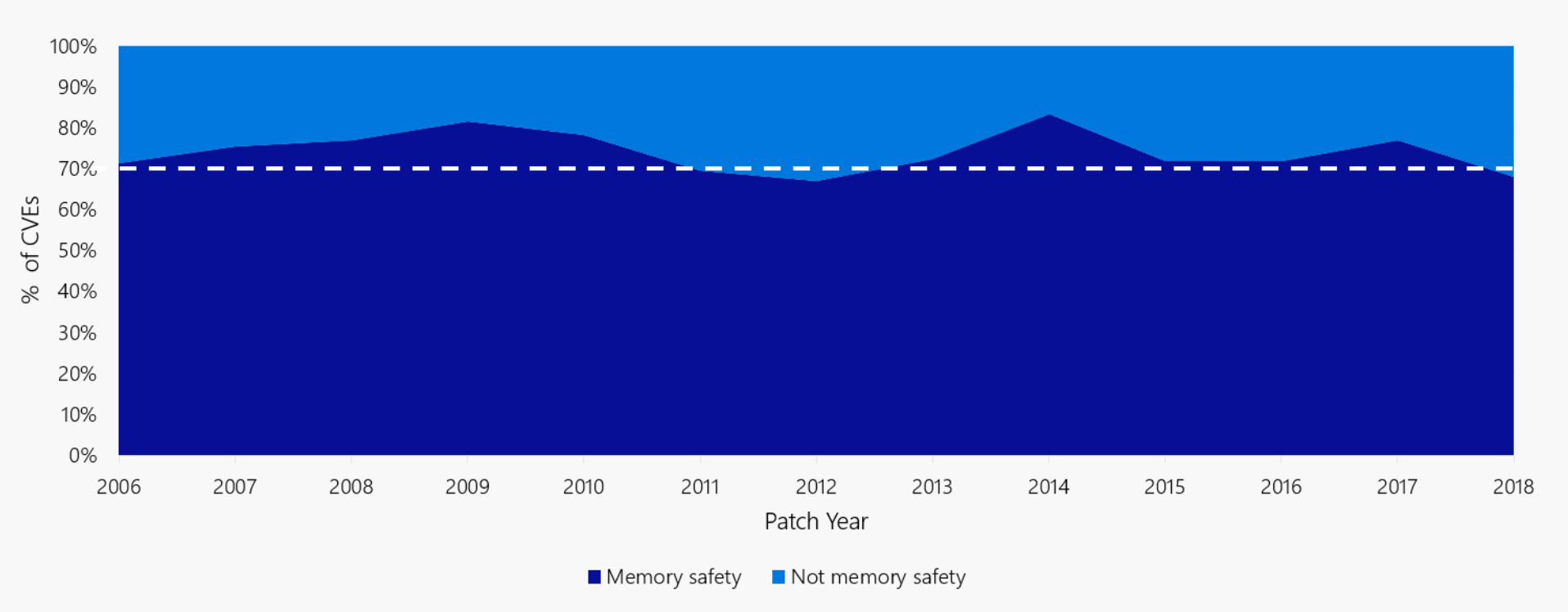
Huge Performance Gaps



Saman Amarasinghe, MIT 6.172 “Performance Engineering”. 2009

And Persistent Correctness Gaps

"The majority of vulnerabilities fixed and with a CVE assigned are caused by developers inadvertently inserting memory corruption bugs into their C and C++ code."



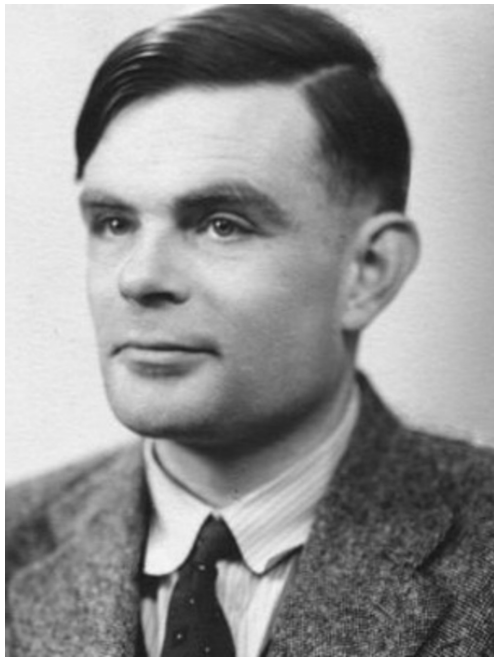
Microsoft Security Response Center. "A proactive approach to more secure code." 2019

Recap

1. Developers mostly comprehend/debug code
2. Software ecosystems are complex at all scales
3. The hardware is changing and software often doesn’t exploit it well
4. Bugs aren’t getting any better

The Long View

Alan Turing

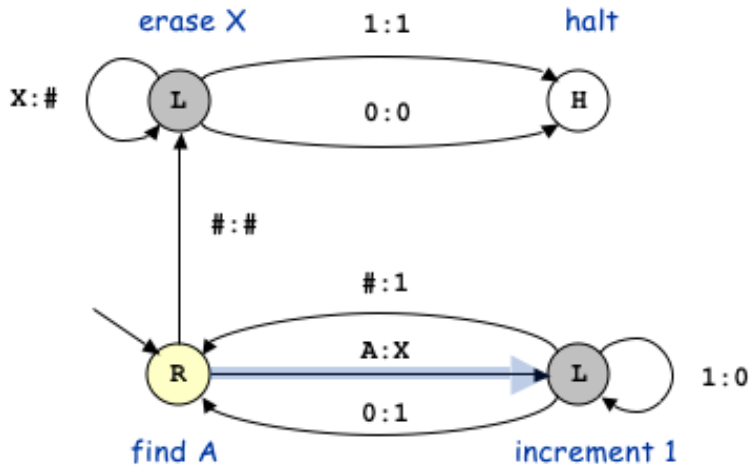


"On Computable Numbers" 1937

Alonzo Church

"A set of postulates for the foundation of logic", 1932

Turing machines



Lambda calculus

$$
\begin{aligned}
[x \to y]\, x &= y \\
[x \to y]\, z &= z \\
[x \to y]\, \lambda\, z\, .\, x &= \lambda\, z\, .\, y \\
[x \to y]\, \lambda\, y\, .\, x\, y &= \lambda\, y'\, .\, y\, y' \\
[x \to y]\, x\, (\lambda\, x\, .\, x) &= y\, (\lambda\, x\, .\, x)
\end{aligned}
$$

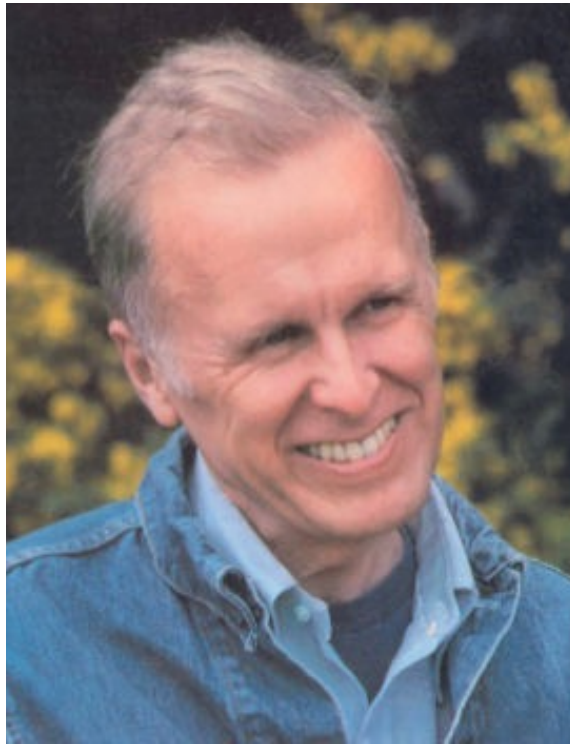
Grace Hopper
HOPL Keynote, 1978

On assembly:

I think I spent 20 years fighting the "Establishment." In the early years of programming languages, the most frequent phrase we heard was that the only way to program a computer was in octal. Of course, a few years later a few people admitted that maybe you could use assembly language.

On compilers:

At that time, the Establishment told us that a computer could not write a program; it was totally impossible; that all that computers could do was arithmetic; that it had none of the imagination and dexterity of a human being. I kept trying to explain that we were wrapping up the human being's dexterity in the program that he wrote.



John Backus,
"History of FORTRAN"
1978

Prior to FORTRAN, most source language operations were not machine operations. Large inefficiencies in looping and computing addresses were masked by time spent in floating point subroutines.

The advent of the 704 with built-in floating point and indexing radically altered the situation. …It increased the problem of generating efficient programs by an order of magnitude by speeding up floating point operations by a factor of ten and thereby leaving inefficiencies nowhere to hide. This caused us to regard the design of the translator as the real challenge, not the simple task of designing the language.

Alan Perlis,

“The American Side of the Development of Algol”
1978

Algol introduced into programming languages such terms as type, declaration, identifier, for statement, while, if then else, switch, the begin end delimiters, block, call by value and call by name, typed procedures, declaration scope, dynamic arrays, side effects, global and local variables.

Algol was strongly derived from FORTRAN and its contemporaries. The logic, arithmetic and data organizations were close to those then being designed into real computers. Certain simple generalizations of computer instructions such as switch, for statement, and if statements were included because their semantics and computer processing were straight-forward consequences of single statement processing.

Ken Thompson,

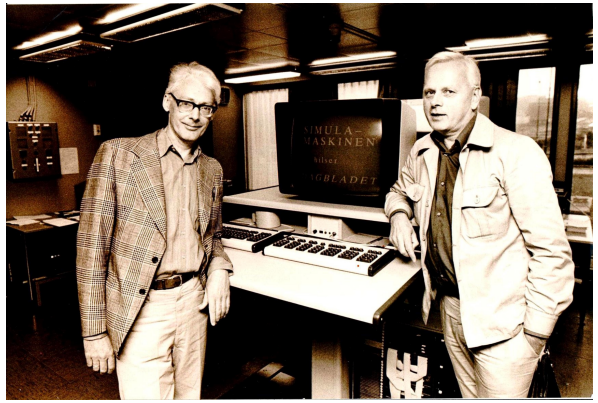
Dennis Ritchie

“The Development of the C Language”

1993

C fits firmly in the traditional procedural family typified by Fortran and Algol 60. It is ‘close to the machine’ in that the abstractions it introduces are readily grounded in the concrete data types and operations supplied by conventional computers.

The most important [historical accident] has been the tolerance of C compilers to errors in type. C evolved from typeless languages. It did not suddenly appear to its earliest users as an entirely new language with its own rules; instead we continually had to adapt existing programs as the language developed, and make allowance for an existing body of code.



Kristen Nygaard and Ole-Johan Dahl
“The Development of SIMULA Languages”, 1978

Our first main task was to carry out resonance absorption calculations related to the construction of Norway's first nuclear reactor. Monte Carlo simulation methods were successfully introduced instead in 1949-1950. The necessity of using simulation and the need of a language for system description was the direct stimulus for SIMULA.

When writing simulation programs we had observed that processes often shared a number of common properties, both in data attributes and actions, but were structurally different in other respects so that they had to be described by separate declarations. Such partial similarity fairly often applied to processes in different simulation models, indicating that programming effort could be saved by somehow preprogramming the common properties.

Bjarne Stroustrup
"A History of C++: 1979-1991", 1993

[Simula's] class concept allowed me to map my application concepts into the language constructs in a direct way. The way Simula classes can act as coroutines made the inherent concurrency of my application easy to express.

The implementation of Simula, however, did not scale in the same way and as a result the whole project came close to disaster. The cost arose from several language features and their interactions: run-time type checking, guaranteed initialization of variables, concurrency support, and garbage collection of both user-allocated objects and procedure activation records.

Sun Microsystems,
1997

The team originally considered using C++, but rejected it for several reasons. They decided that C++’s complexity led to developer errors. The language's lack of garbage collection meant that programmers had to manually manage system memory, a challenging and error-prone task. The team also worried about the C++ language's lack of portable facilities for security, distributed programming, and threading. Finally, they wanted a platform that would port easily to all types of devices.

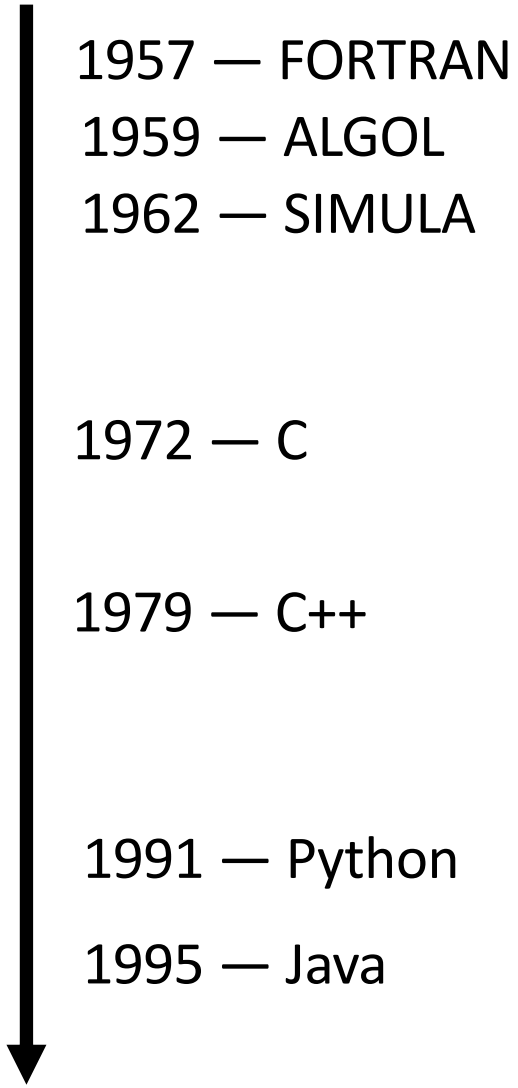
— Wikipedia

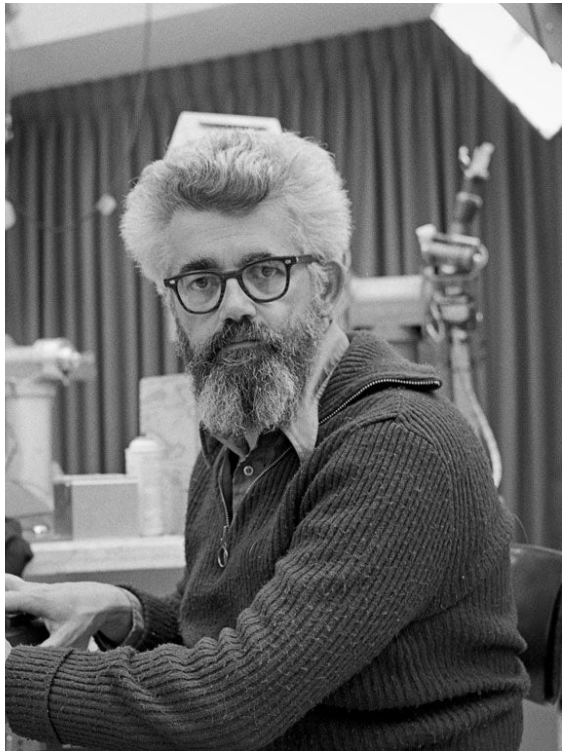
Guido van Rossum
“The Making of Python”, 2003

My initial goal for Python was to serve as a second language for people who were C or C++ programmers, but who had work where writing a C program was just not effective.

Maybe it was something you'd do only once. It was the sort of thing you'd prefer to write a shell script for, but when you got into the writing details, you found that the shell was not the ideal language—you needed more data structures, more namespaces, or maybe more performance. The first sound bite I had for Python was, "Bridge the gap between the shell and C."

Turing languages





John McCarthy,
“History of LISP” 1978

My own research in artificial intelligence [in 1958]… involved representing information about the world by sentences in a suitable formal language and a reasoning program that would decide what to do by making logical inferences. Representing sentences by list structure seemed appropriate and a list-processing language also seemed appropriate for programming the operations involved in deduction.

…One needs a notation for functions, and it seemed natural to use the λ-notation of Church (1941). I didn't understand the rest of his book, so I wasn't tempted to try to implement his more general mechanism for defining functions.

Peter Landin,
“The Next 700 Programming Languages” 1966

The languages people use to communicate with computers differ in their intended aptitudes, towards either a particular application area, or a particular phase of computer use (high level programming, program assembly, job scheduling, etc). The question arises, do the idiosyncrasies reflect basic logical properties of the situations that are being catered for? Or are they accidents of history and personal background that may be obscuring fruitful developments?

ISWIM is an attempt at a general purpose system for describing things in terms of other things, that can be problem-oriented by appropriate choice of "primitives." A possible first step in the research program is 1700 doctoral theses called "A Correspondence between ***x*** and Church's λ-notation.”

Robin Milner,

“A Metalanguage for Interactive Proof in LCF” 1978

The principal aims in designing ML were to make it impossible to prove non-theorems yet easy to program strategies for performing proofs.

A strategy—or recipe for proof—could be something like “induction on ***f*** and ***g*** , followed by assuming antecedents and doing case analysis, all interleaved with simplification”. This is imprecise—analysis of what cases? what kind of induction, etc, etc.—but these in turn may well be given by further recipes, still in the same style.

Hudak et al.

"A History of Haskell: Being Lazy with Class" 2007

The simplicity and elegance of functional programming captivated the present authors. Lazy evaluation— with its direct connection to the pure, call-by-name lambda calculus, the remarkable possibility of representing and manipulating infinite data structures, and addictively simple and beautiful implementation techniques—was like a drug.

Turing languages

1957 — FORTRAN
1959 — COBOL, ALGOL
1962 — SIMULA

1972 — C, Smalltalk

1979 — C++

1991 — Python

1995 — Java

Church languages

1959 — LISP

1966 — ISWIM

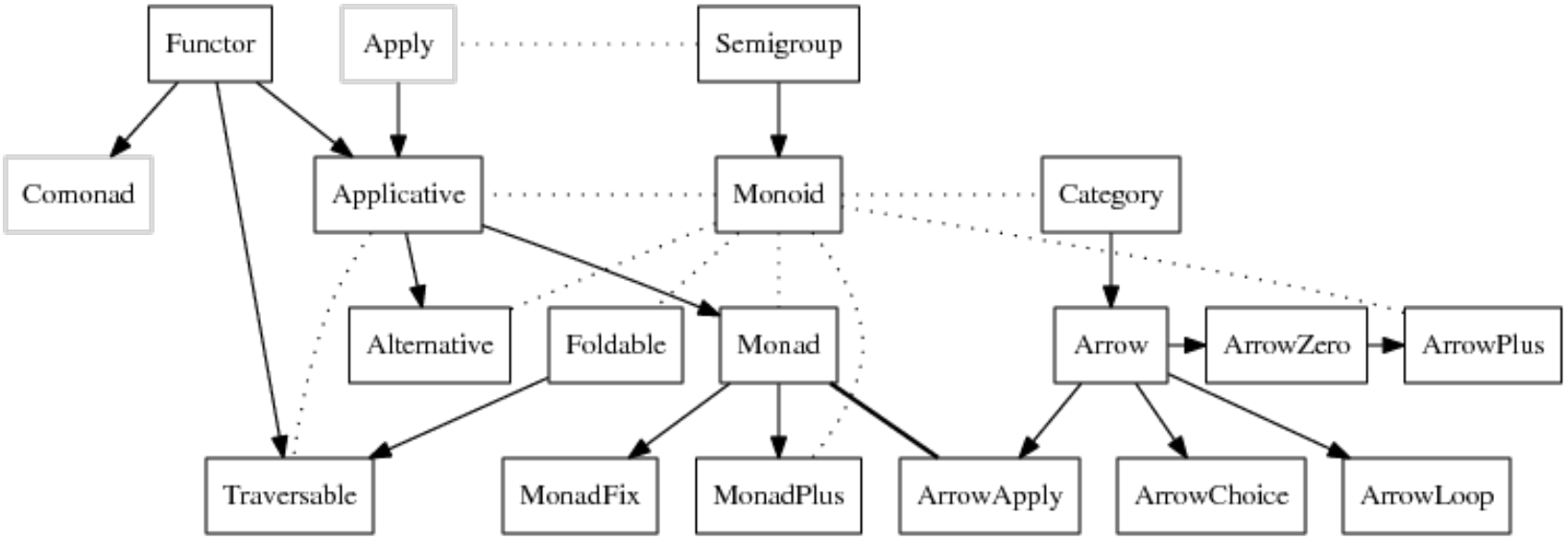
1972 — Prolog

1978 — ML, FP

1985 — Miranda

1990 — Haskell

Church Languages Are Unfamiliar




```
Couldn't match type `k0' with `b'
  because type variable `b' would escape its scope
This (rigid, skolem) type variable is bound by
  the type signature for
    groupBy :: Ord b => (a -> b) -> Set a -> Set (b, [a])
The following variables have types that mention k0
```

PL Theory is Unfamiliar (and Dense)

$$\frac{\begin{array}{c}\Sigma_0;\Gamma_1 \vdash A = \mathsf{D}\ \bar{v} : \mathsf{Set}_n \qquad \Gamma = \Gamma_1(x : A)\Gamma_2 \\ \mathsf{data}\ \mathsf{D}\ \Delta : \mathsf{Set}_n\ \mathsf{where}\ \mathsf{c_i}\ \Delta_i\ [\bar{j_i} \mid b_i] \in \Sigma_0 \qquad \exists k.\ [\bar{j_k} \mid b_k] \neq []\end{array}}{\begin{array}{c}\left(\begin{array}{c}\Delta_i' = \Delta_i(\bar{j_i} : \mathbb{I})[\bar{v} \,/\, \Delta] \qquad \bar{q}_i = \hat{\Delta}_i[\bar{j_i} \mid b_i][\bar{v} \,/\, \Delta] \\ \rho_i = \mathbb{1}_{\Gamma_1} \uplus [\mathsf{c_i}\ \bar{q}_i \,/\, x] \qquad \rho_i' = \rho_i \uplus \mathbb{1}_{\Gamma_2} \\ \Theta_i = \textsc{boundary}(\bar{j_i}); \Theta \\ \Sigma_{i-1};\Gamma_1\Delta_i'(\Gamma_2\rho_i) \vdash \mathsf{f}\ \bar{q}\rho_i' := Q_i : C\rho_i' \mid \Theta_i \rightsquigarrow \Sigma_i\end{array}\right)_{i=1\ldots n} \\ \Delta_{\mathsf{hc}} = (r : \mathbb{I})(u : \mathbb{I} \to \mathsf{Partial}\ r\ (\mathsf{D}\ \bar{v}))(u_0 : \mathsf{D}\ \bar{v}\ [\, r \mapsto u\ \mathsf{i0}\,]) \\ \rho_{\mathsf{hc}} = \mathbb{1}_{\Gamma_1} \uplus [\mathsf{hcomp}\ r\ u\ u_0 \,/\, x] \qquad \rho_{\mathsf{hc}}' = \rho_{\mathsf{hc}} \uplus \mathbb{1}_{\Gamma_2} \\ \Sigma_n;\Gamma_1\Delta_{\mathsf{hc}}(\Gamma_2\rho_{\mathsf{hc}}) \vdash \mathsf{f}\ \bar{q}\rho_{\mathsf{hc}}' := Q_{\mathsf{hc}} : C\rho_{\mathsf{hc}}' \mid (r = 1); \Theta \rightsquigarrow \Sigma_{n+1}\end{array}}{\Sigma_0;\Gamma \vdash \mathsf{f}\ \bar{q} := \mathsf{case}_x \left\{ \begin{array}{l} \mathsf{c_1}\ \bar{q}_1 \mapsto Q_1; \ldots; \mathsf{c_n}\ \bar{q}_n \mapsto Q_n \\ \mathsf{hcomp}\ r\ u\ u_0 \mapsto Q_{\mathsf{hc}} \end{array} \right\} : C \mid \Theta \rightsquigarrow \Sigma_{n+1}}$$

Vezzosi et al. “Cubical Agda: A Dependently Typed Programming Language with Univalence and Higher Inductive Types” ICFP ‘19

The Future

Change Is Happening

- Software systems tend to be big, slow, and buggy
- There are broad forces at work that are compelling changes
  - Security and the increasing dependence on software
  - Revolution in the underlying hardware
  - A perpetual shortage of skilled programmers

Change Is Coming

- Software systems are big, slow, and buggy
  - And getting more so

- There are broad forces at work that are compelling changes
  - Security and the increasing dependence on software
    - Software verification
  - Revolution in the underlying hardware
    - Moving beyond Turing languages
  - A perpetual shortage of skilled programmers
    - Automation of programming

This Course

- Convey ethos of programming languages as a topic of study
  - And some of the important techniques
- Illustrate these ideas with examples
  - From current practice and research
- See the future before it happens

Tackling Complexity Through Modularity

Modular design is the key to successful programming. When writing a modular program to solve a problem, one first divides the problem into subproblems, then solves the subproblems, and finally combines the solutions.

The ways in which one can divide up the original problem depend directly on the ways in which one can glue solutions together. Therefore, to increase one's ability to modularize a problem conceptually, one must provide new kinds of glue in the programming language.

— John Hughes, "Why Functional Programming Matters" 1989

```
fun innerproduct(a, b, n):
  c := 0
  for i := 1 step 1 until n do
    c := c + a[i] * b[i]
  return c
```

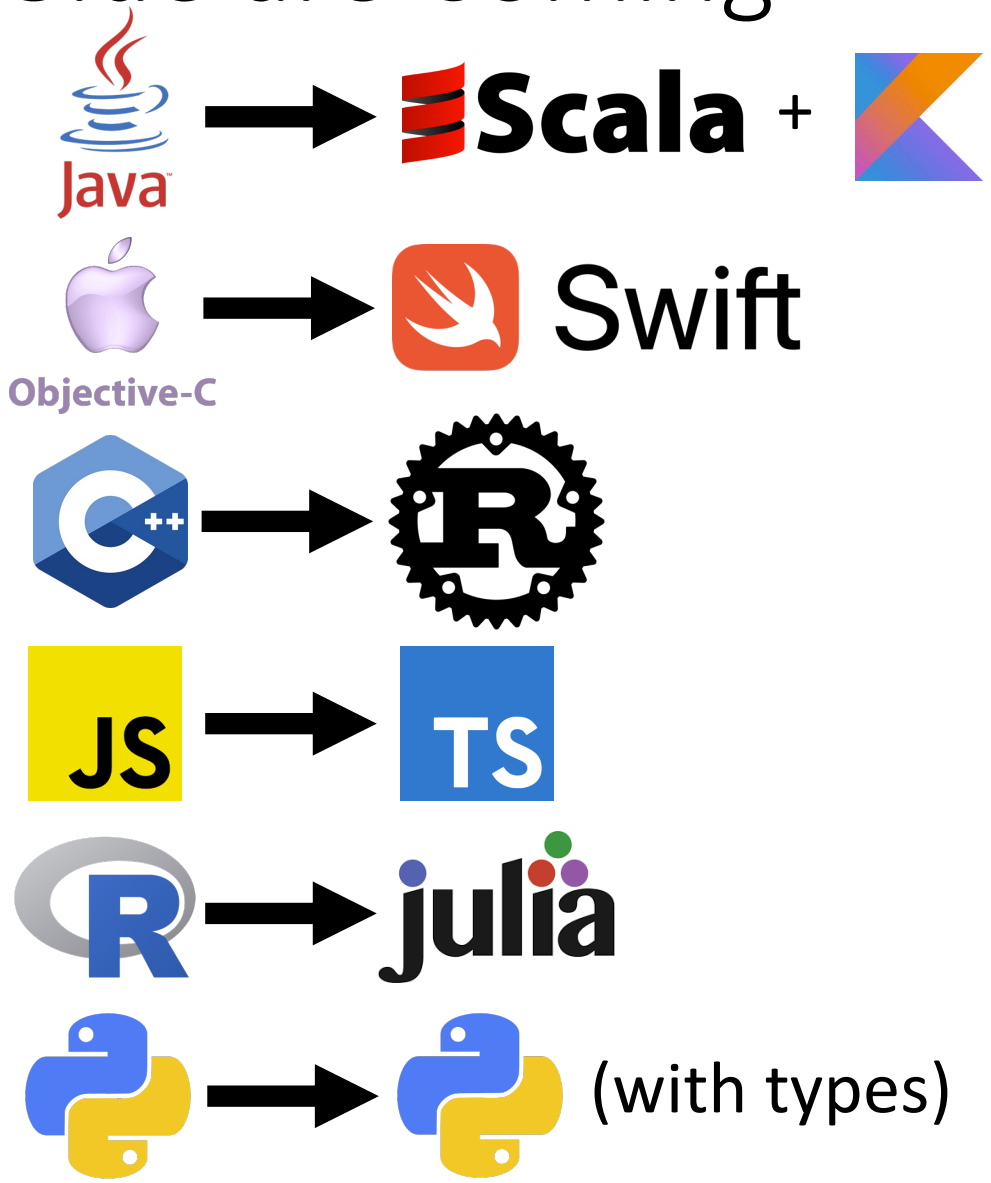
- Statements operate on invisible state
- Computes word-at-a-time by repetition of assignment/modification
- Requires names for arguments, iterator, return value

```
let innerproduct = zip |> (map *) |> (reduce +)
```

- Built from composable functions (map, reduce, pipe)
- Operates on whole conceptual units (lists), no repeated steps
- No names for arguments or temporaries

Radically Different Hardware is Here

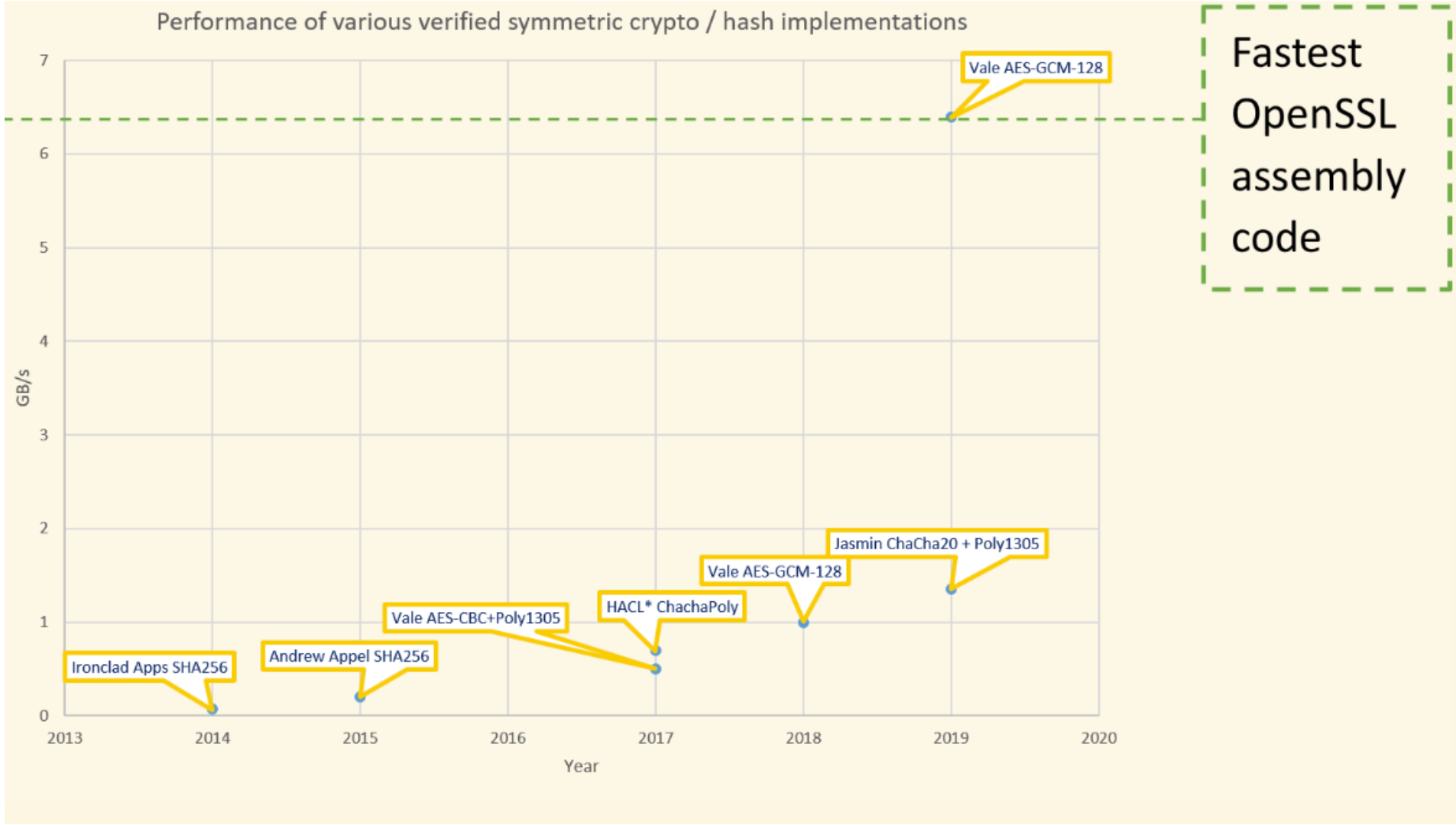
New Kinds of Glue are Coming



More Reliable Software is Coming

> Messenger used to receive bugs reports on a daily basis; since the introduction of Reason, there have been a total of 10 bugs (that's during the whole year, not per week)! Refactoring speed went from days to hours to dozens of minutes.
>
> — “Messenger.com Now 50% Converted to Reason” 2017

> Being able to encode constraints of your application in the type system makes it possible to refactor, modify, or replace large swaths of code with confidence. Rust's error model forces developers to handle every corner case. [Our system] needs very little attention. We were able to leave it running without any issues through the holiday break.
>
> — “Rust at OneSignal” 2017


Performance of various verified symmetric crypto / hash implementations
GB/s
Year
0
1
2
3
4
5
6
7
2013
2014
2015
2016
2017
2018
2019
2020
Ironclad Apps SHA256
Andrew Appel SHA256
Vale AES-CBC+Poly1305
HACL* ChachaPoly
Vale AES-GCM-128
Jasmin ChaCha20 + Poly1305
Vale AES-GCM-128
Fastest OpenSSL assembly code

Summary

- The world of software will change significantly

- The changes are driven by
  - New ideas in programming
  - Changes in underlying hardware
  - Changes in needs (e.g., security)

- In this course we will focus on
  - The new programming ideas
  - And the intellectual tools to understand the next generation of ideas