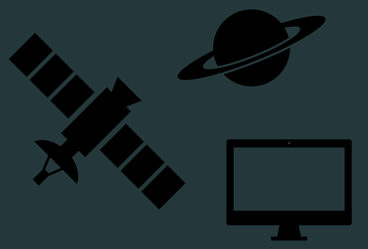
ソフトウェアの未来を科学する

Rust に誘われて

松下 祐介　京都大学・MPI-SWS

2026年9月5日　第59回情報科学若手の会



Sciencing the Future of Software

Allured by Rust

Yusuke Matsushita Kyoto University & MPI-SWS

Sept 5, 2026 59th Joho-kagaku Wakate-no-kai

About Me

About Me

- **Yusuke Matsushita　松下 祐介**
  - July 15, 1996, Osaka

About Me

- **Yusuke Matsushita　松下 祐介**
  - July 15, 1996, Osaka
- **’15–’24　Bachelor, Master, Ph.D. at UTokyo**
  - **Computer science — Programming languages**
    - Supervised by **Prof. Naoki Kobayashi**

About Me

- **Yusuke Matsushita　松下 祐介**
  - July 15, 1996, Osaka
- **’15–’24　Bachelor, Master, Ph.D. at UTokyo**
  - **Computer science — Programming languages**
    - Supervised by **Prof. Naoki Kobayashi**
- **’25–　Assist. Prof. at Hakubi, KyotoU**
  - Focus on **Rust**
  - ’26–　**Visiting scientist** at **MPI-SWS**
    - **Germany, Prof. Derek Dreyer**

About Me

Google Scholar SIGN IN

Yusuke Matsushita

FOLLOW

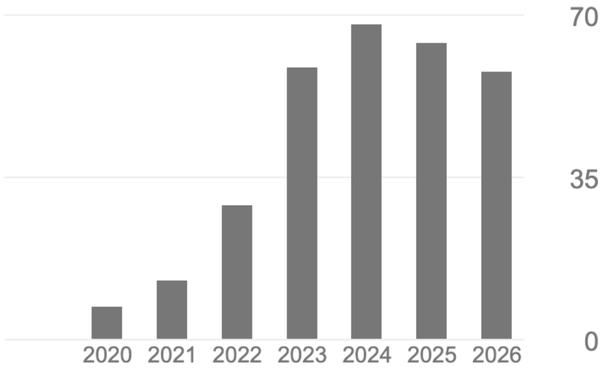
GET MY OWN PROFILE

Kyoto University
Verified email at fos.kuis.kyoto-u.ac.jp - Homepage
Computer Science Programming Languages Machine Learning

TITLE	CITED BY	YEAR
RustHorn: CHC-based Verification for Rust Programs Y Matsushita, T Tsukada, N Kobayashi ACM Transactions on Programming Languages and Systems (TOPLAS) 43 (4), 1-54	108	2021
RustHornBelt: A Semantic Foundation for Functional Verification of Rust Programs with Unsafe Code Y Matsushita, X Denis, JH Jourdan, D Dreyer Proceedings of the 43rd ACM SIGPLAN Conference on Programming Language …	94	2022
RustHorn: CHC-Based Verification for Rust Programs Y Matsushita, T Tsukada, N Kobayashi European Symposium on Programming (ESOP), 484-514	65	2020
Nola: Later-Free Ghost State for Verifying Termination in Iris Y Matsushita, T Tsukada Proceedings of the ACM on Programming Languages 9 (PLDI)	7	2025

Cited by

	All	Since 2021
Citations	298	291
h-index	5	5
i10-index	3	3



Public access VIEW ALL

0 articles 6 articles

About Me

PLDI Review Committee PLDI Research Papers

Benjamin Mariano
The University of Texas at Austin, Texas, USA
United States

Guido Martínez
Microsoft Research
United States

Yusuke Matsushita
Kyoto University
Japan

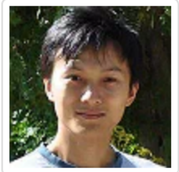
Jedidiah McClurg
Cornell University
United States

Roland Meyer
TU Braunschweig
Germany

Mae Milano
Princeton University
United States

Program Committee POPL

Yannick Zakowski
Inria
France



Yingfei Xiong
Peking University
China

Youyou Cong
Institute of Science Tokyo
Japan

Yu Feng
University of California at Santa Barbara
United States

Yu-Fang Chen
Academia Sinica
Taiwan

Yusuke Matsushita
Kyoto University
Japan

How I Became What I Am

How I Became What I Am

- Elementary school — Squeak, Visual Basic

How I Became What I Am

- Elementary school — Squeak, Visual Basic

- Junior high school — HSP, C++, Programming contests, C#

How I Became What I Am

- Elementary school — Squeak, Visual Basic 
- Junior high school — HSP, C++, Programming contests, C# 
- Senior high school — **Haskell, Category theory, PL basics** 

How I Became What I Am

- Elementary school — Squeak, Visual Basic 
- Junior high school — HSP, C++, Programming contests, C# 
- Senior high school — **Haskell, Category theory, PL basics** 
- Freshman, sophomore, junior — **Rust, PL theory** 

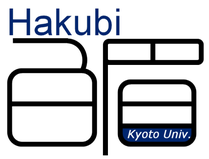
How I Became What I Am

- Elementary school — Squeak, Visual Basic 
- Junior high school — HSP, C++, Programming contests, C# 
- Senior high school — **Haskell, Category theory, PL basics** 
- Freshman, sophomore, junior — **Rust, PL theory** 
- Senior — Kobayashi Lab, **RustHorn** for my senior thesis 

How I Became What I Am

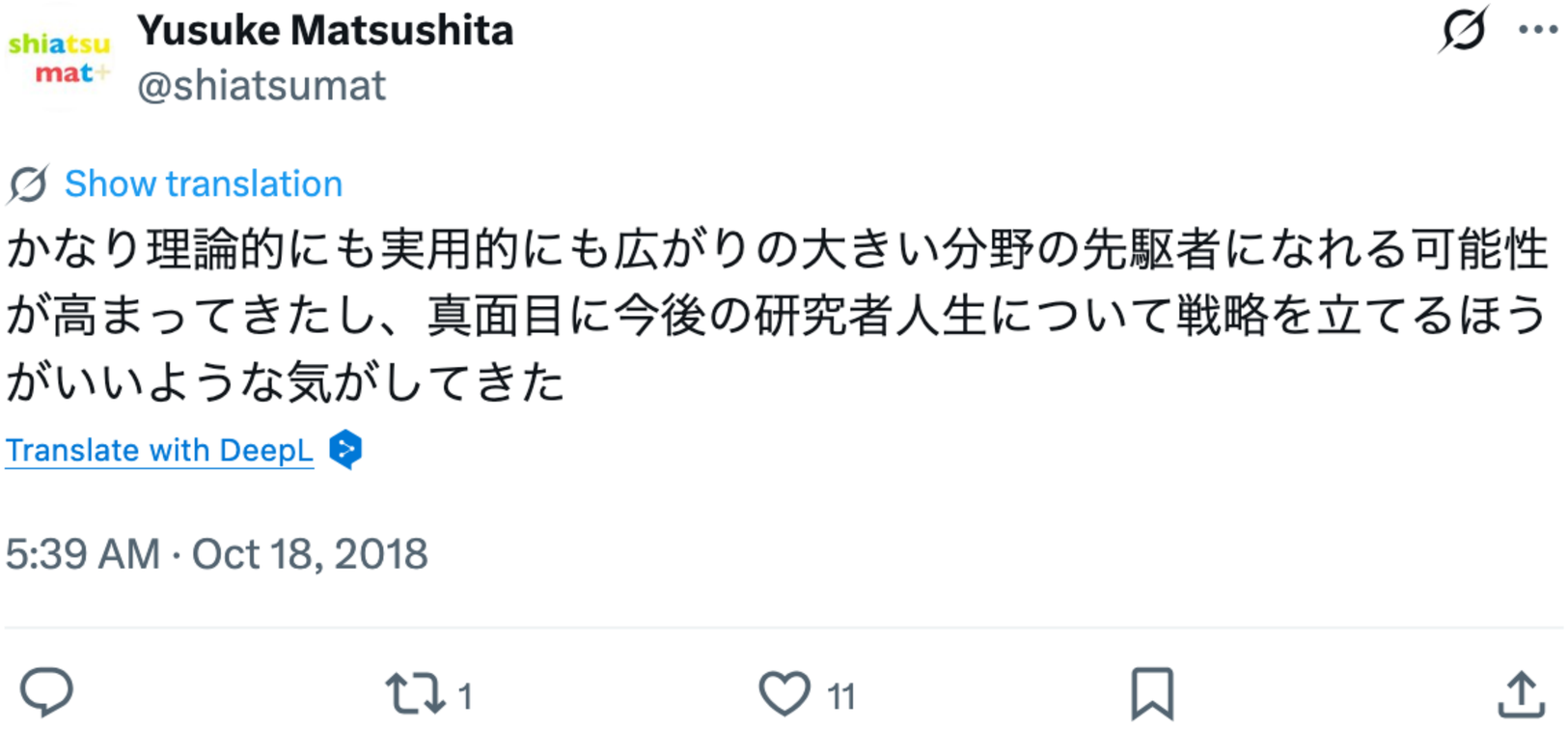
- Elementary school — Squeak, Visual Basic 
- Junior high school — HSP, C++, Programming contests, C# 
- Senior high school — **Haskell, Category theory, PL basics** 
- Freshman, sophomore, junior — **Rust, PL theory** 
- Senior — Kobayashi Lab, **RustHorn** for my senior thesis 
- Master — Internship at **MPI-SWS, RustHornBelt** 

How I Became What I Am

- ✦ Elementary school — Squeak, Visual Basic 
- ✦ Junior high school — HSP, C++, Programming contests, C# 
- ✦ Senior high school — **Haskell, Category theory, PL basics** 
- ✦ Freshman, sophomore, junior — **Rust, PL theory** 
- ✦ Senior — Kobayashi Lab, **RustHorn** for my senior thesis 
- ✦ Master — Internship at **MPI-SWS, RustHornBelt** 
- ✦ Ph.D. → Postdoc → **Assist. Prof.** at Hakubi 

When I Discovered the Idea of RustHorn

When I Discovered the Idea of RustHorn 

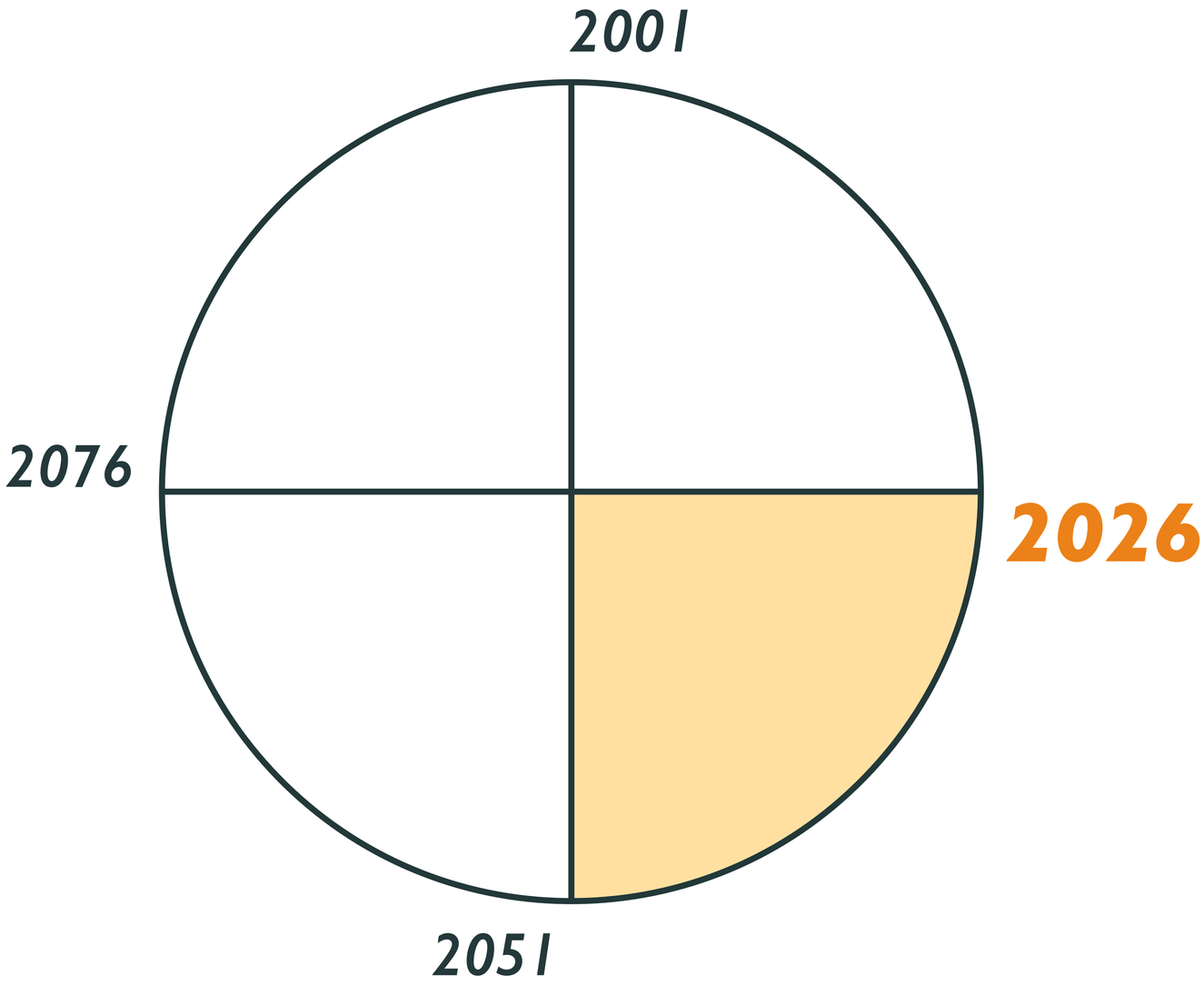


Now I have a strong chance of becoming a pioneer in a field
with significant potential for growth both scientifically and practically;
I'm feeling that I should seriously strategize about my future career as a scientist.

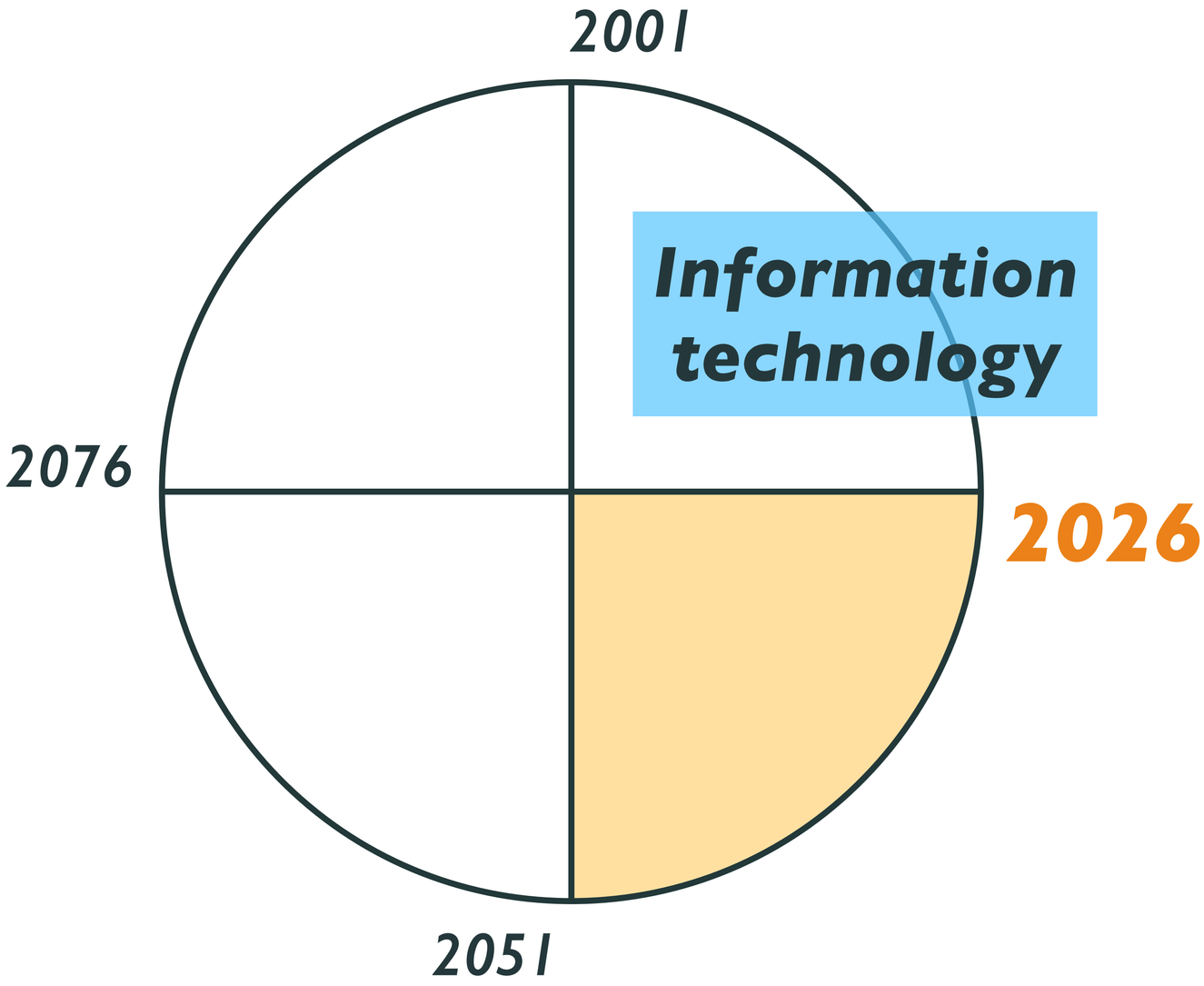
Where Are We?

The 2nd Quarter of the 21th Century

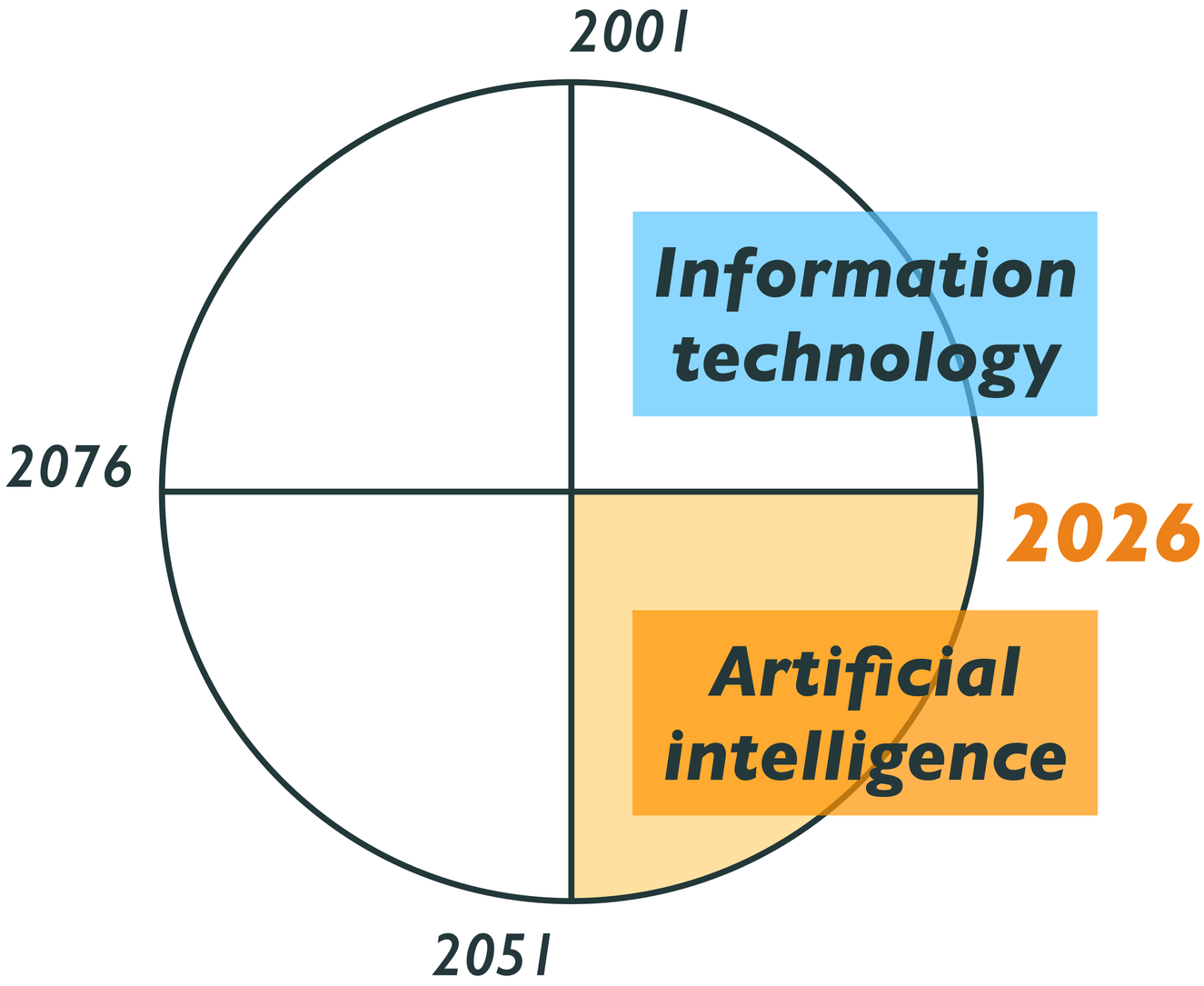
The 2nd Quarter of the 21th Century



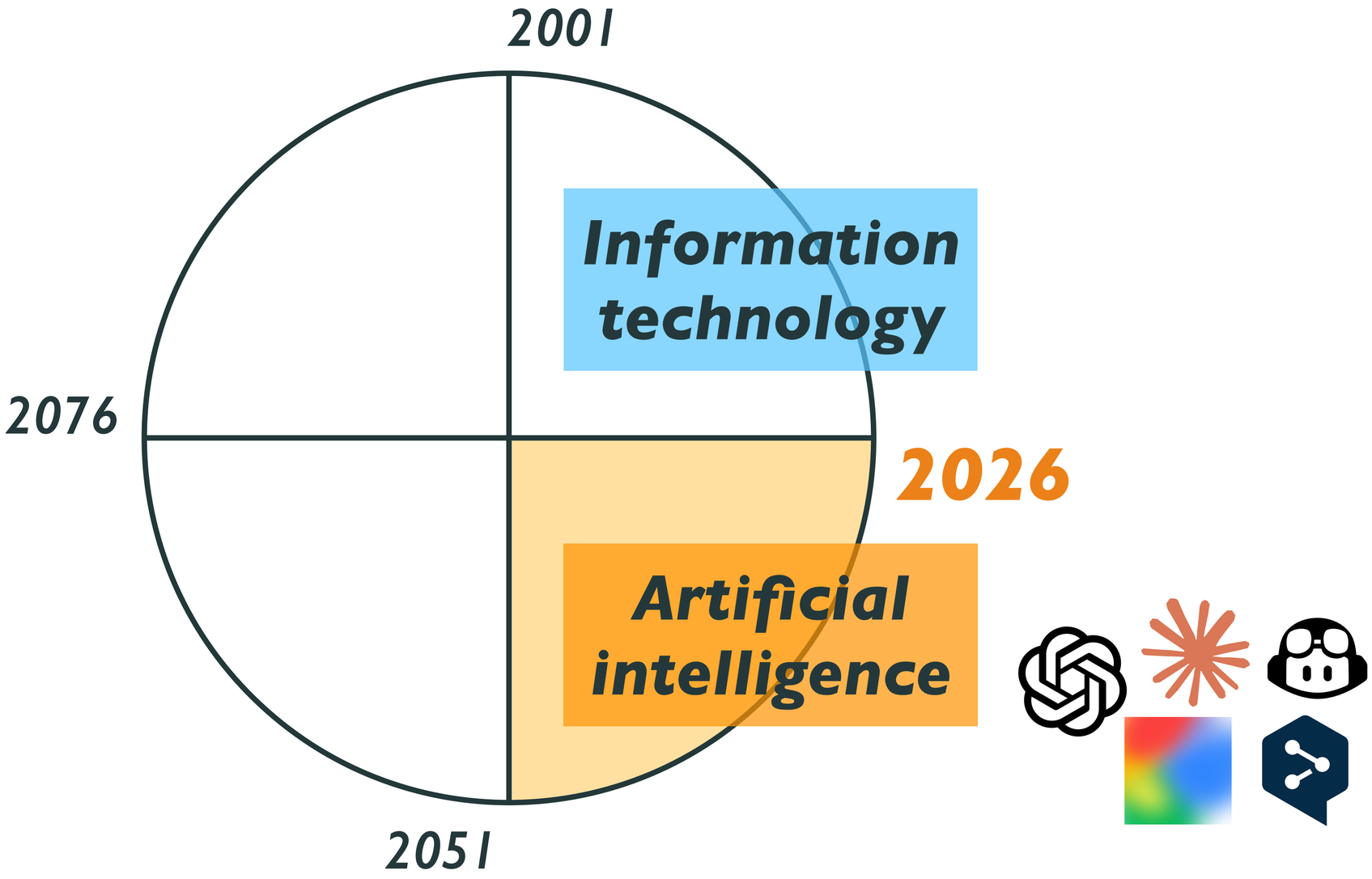
The 2nd Quarter of the 21th Century



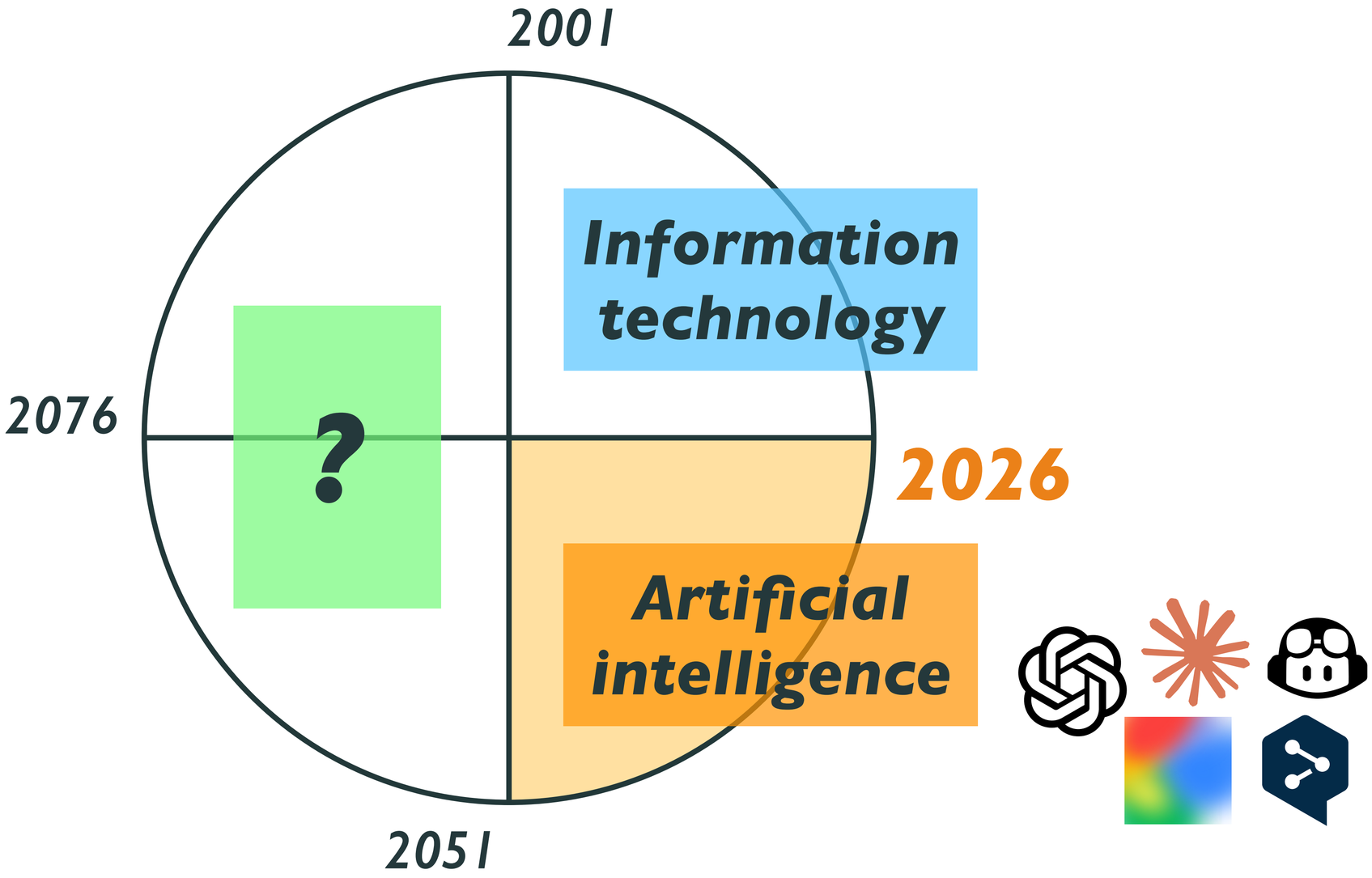
The 2nd Quarter of the 21th Century



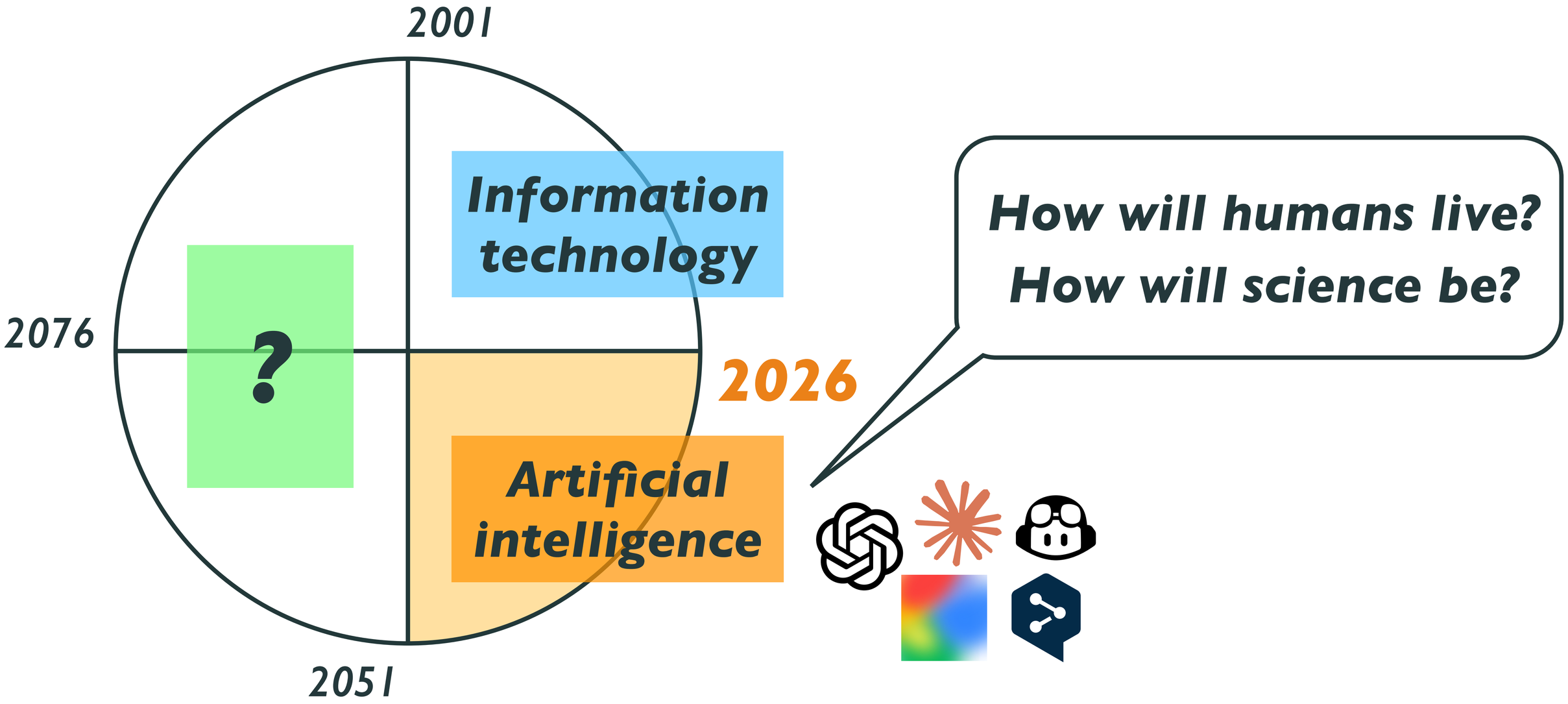
The 2nd Quarter of the 21th Century



The 2nd Quarter of the 21th Century

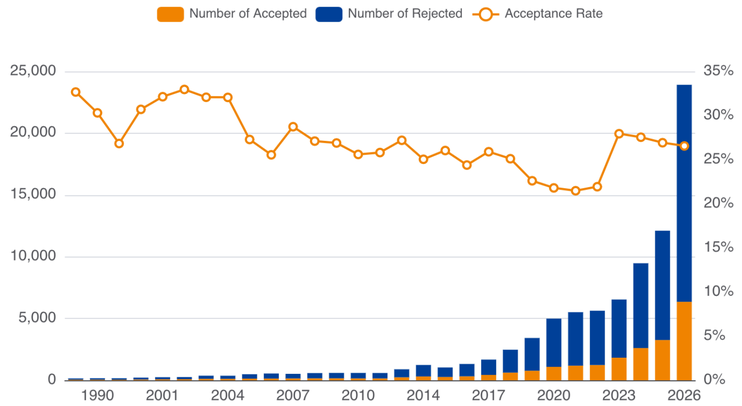


The 2nd Quarter of the 21th Century

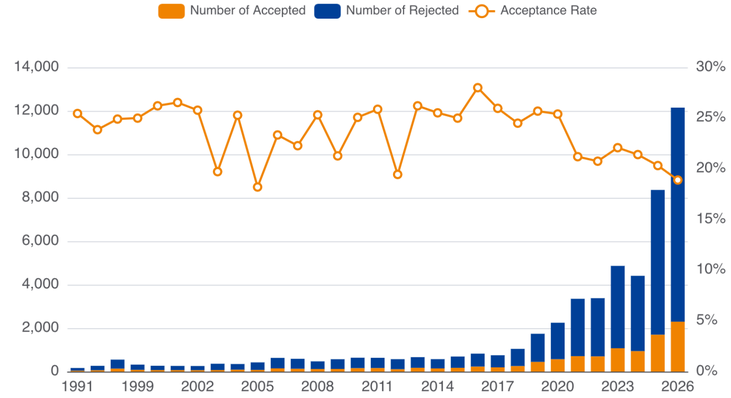


Computer Science Accelerated

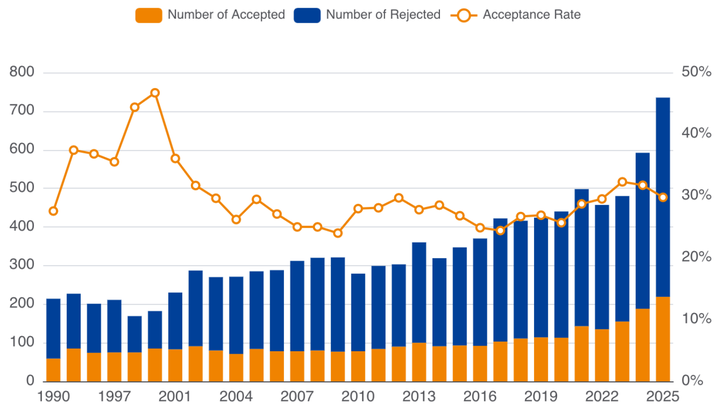
Computer Science Accelerated



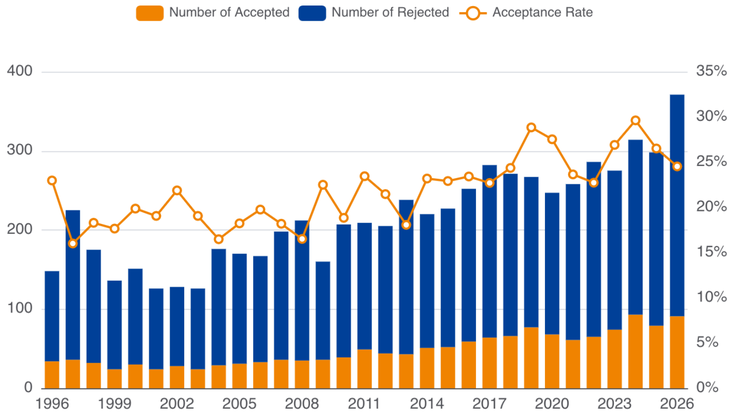
ICML



ACL



STOC



POPL

Source: csconfstats.xoveexu.com

How to Survive This Uncertainty?

How to Survive This Uncertainty?

Think Broad & Flexible

How to Survive This Uncertainty?

Think Broad & Flexible

Learn from Other Fields & History

How to Survive This Uncertainty?

Think Broad & Flexible

Learn from Other Fields & History

Reflect on Human Nature

How to Survive This Uncertainty?

Think Broad & Flexible

Learn from Other Fields & History

Reflect on Human Nature

And you can think and discuss more!

Science of Software

What Was Ancient Human Life Like?

What Was Ancient Human Life Like?

- Full of dangers & uncertainties in nature

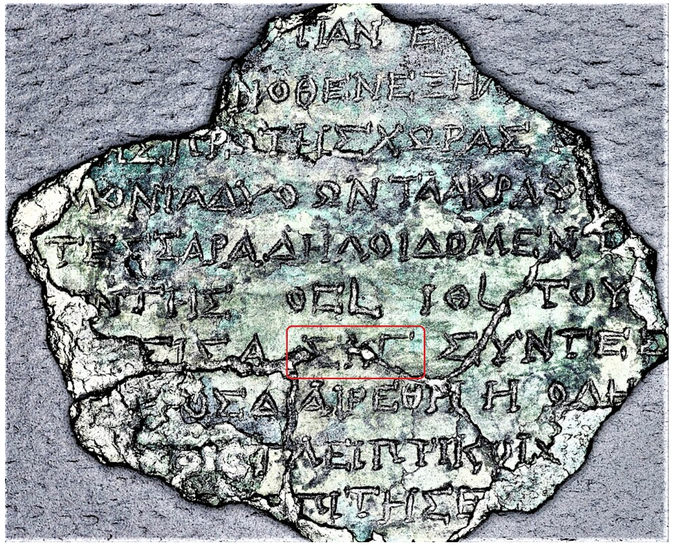
What Was Ancient Human Life Like?

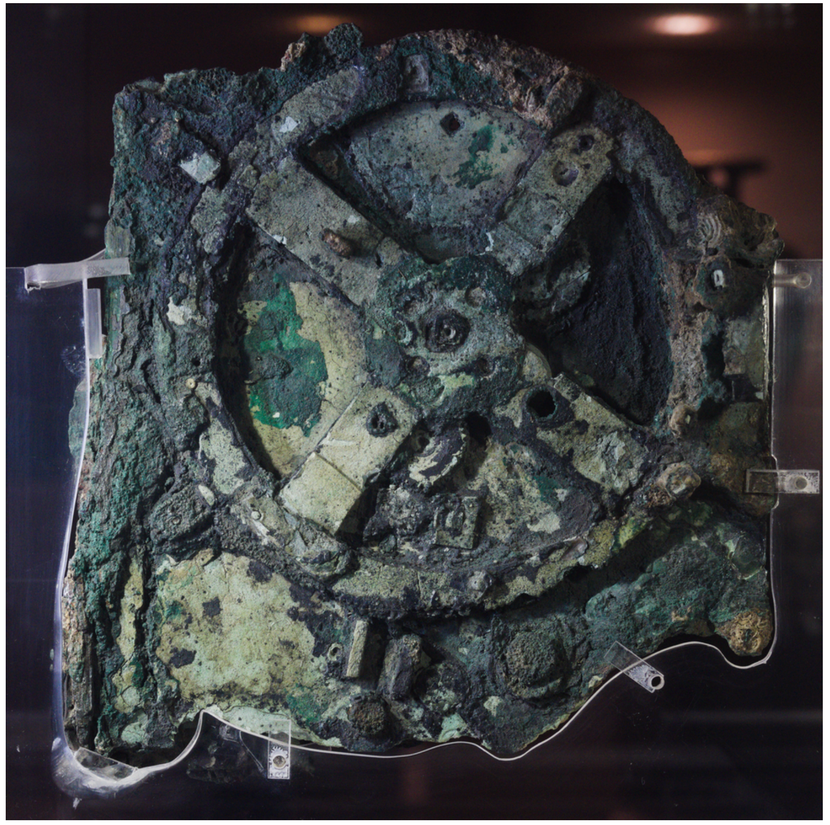
- Full of dangers & uncertainties in nature
- The stars in the sky move in a mysteriously orderly way

Oldest Computer?

Oldest Computer?

- **Antikythera Mechanism** *Ancient Greek, ~150 BC*
  - Models the **solar system**
  - **Predict astronomical positions?**

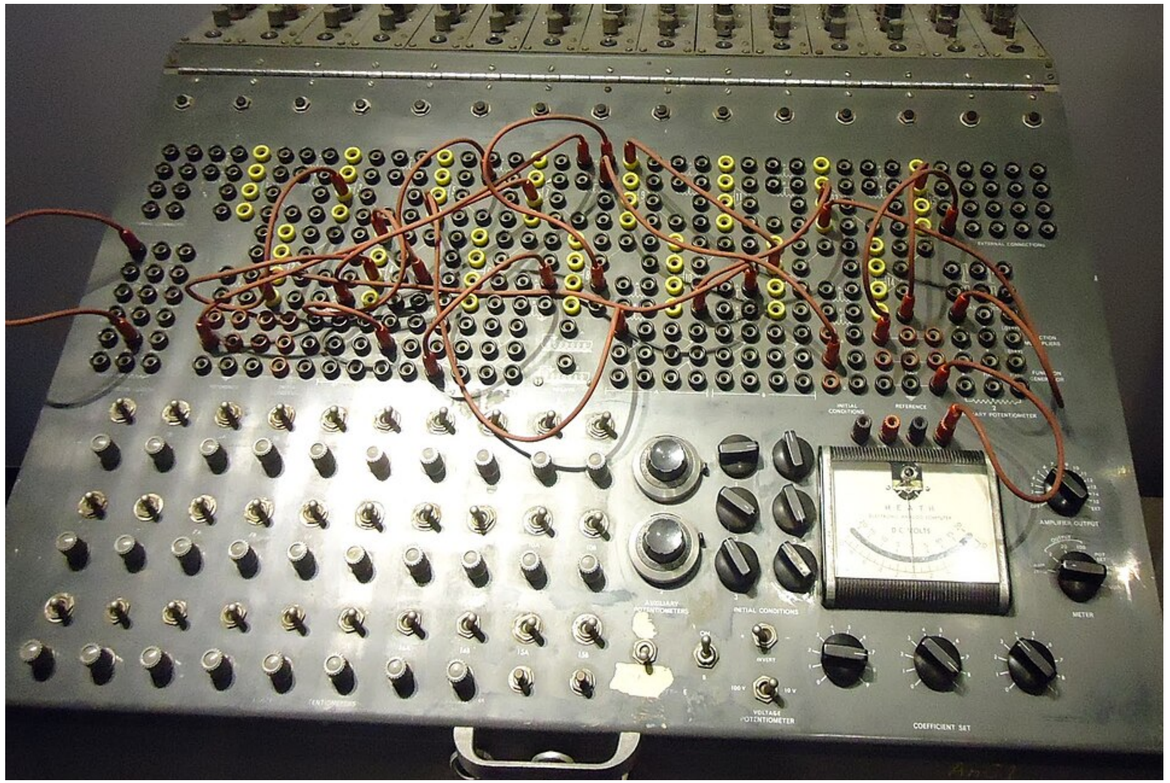


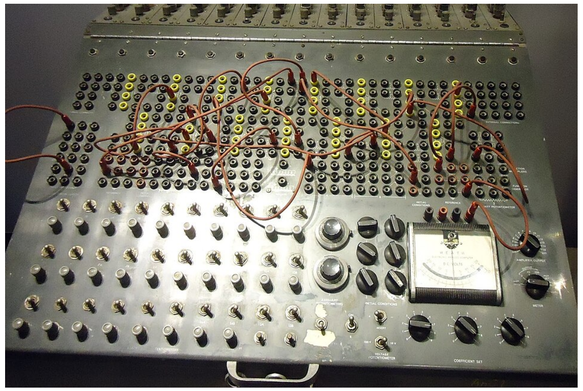


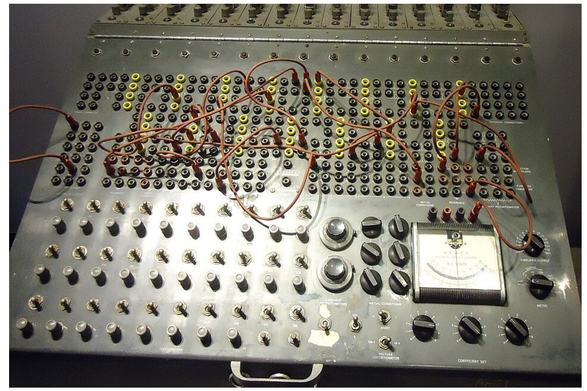
Humans – Machines

Humans – Machines

Humans – Machines

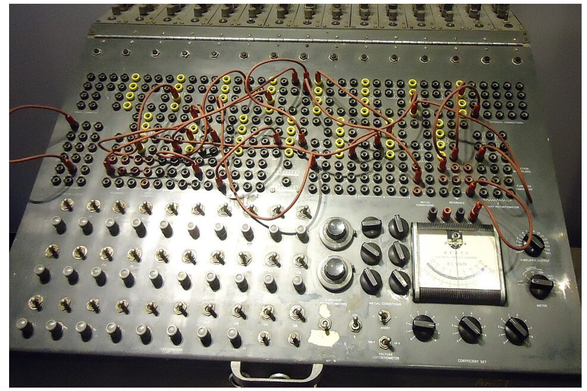






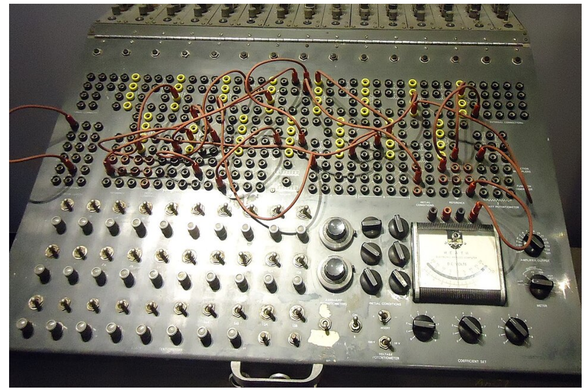
Software

Software



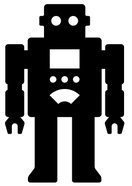
Software

Software



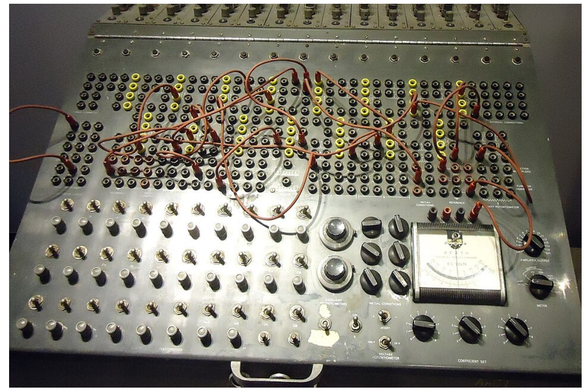
Software embodies human ideals

on finite physical machines



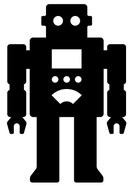
Software

Software



Software embodies human ideals

on finite physical machines



— *Me, Sept 2025*

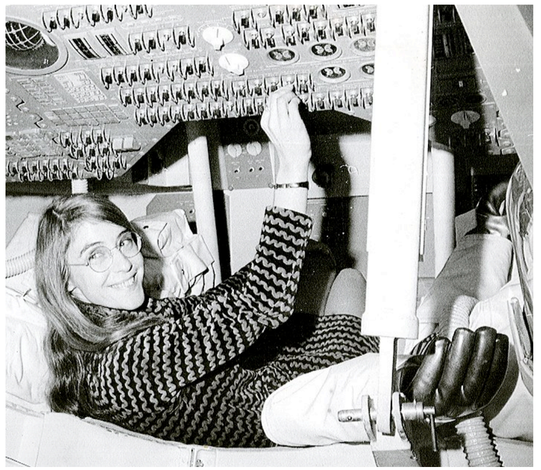
Software Science & Engineering

Software Science & Engineering

- ✦ Universal & pragmatic methodologies
  to develop high-quality, bug-free software

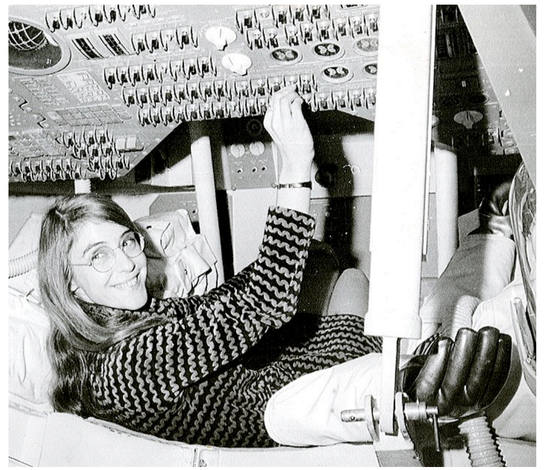
Software Science & Engineering

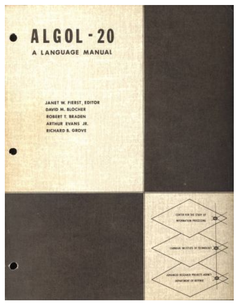
- **Universal & pragmatic methodologies to develop high-quality, bug-free software**
  - M. Hamilton coined "**software engineering**"

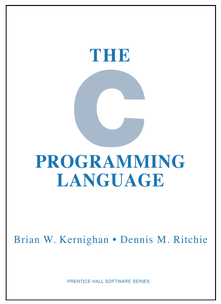


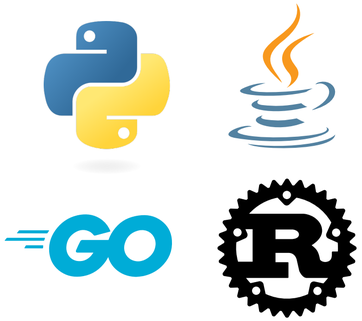
Software Science & Engineering

- **Universal & pragmatic methodologies to develop high-quality, bug-free software**
  - M. Hamilton coined "**software engineering**"
  - **Science — Logic & Mathematics**
  - **Programming languages, types, …**





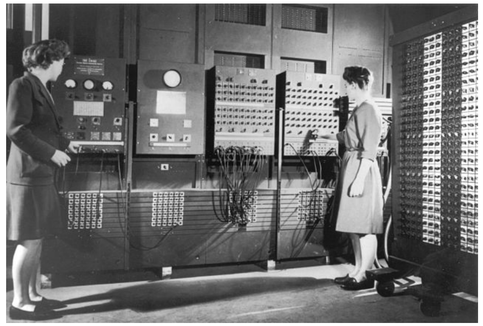




Evolution of Programming

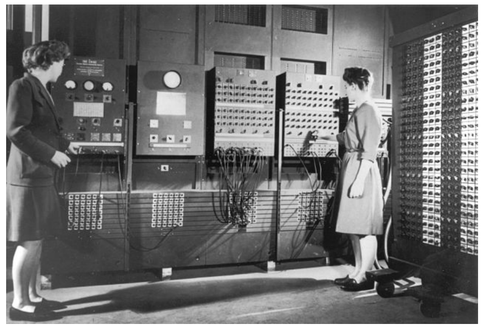
Evolution of Programming

- **1940's Physical settings**
  - Plugboard wiring & switches



Evolution of Programming

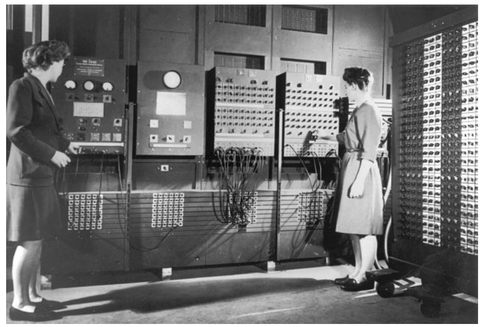
- **1940's Physical settings**
  - Plugboard wiring & switches
- **1947 Assembly languages**
  - **Transliteration** of machine code



```
0013            RESETA  EQU     %00010011
0011            CTLREG  EQU     %00010001

C003 86 13      INITA   LDA A   #RESETA
C005 B7 80 04           STA A   ACIA
C008 86 11              LDA A   #CTLREG
C00A B7 80 04           STA A   ACIA

C00D 7E C0 F1           JMP     SIGNON
```

Evolution of Programming

- **1940's Physical settings**
  - Plugboard wiring & switches

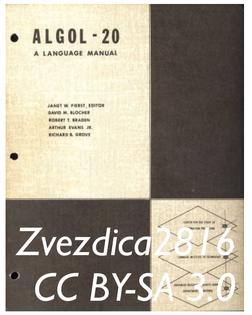


- **1947 Assembly languages**
  - **Transliteration** of machine code

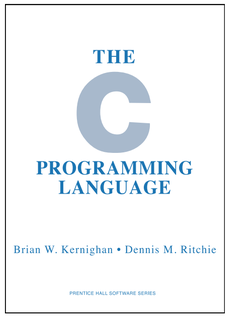
```
0013            RESETA  EQU     %00010011
0011            CTLREG  EQU     %00010001

C003 86 13      INITA   LDA A   #RESETA
C005 B7 80 04           STA A   ACIA
C008 86 11              LDA A   #CTLREG
C00A B7 80 04           STA A   ACIA

C00D 7E C0 F1           JMP     SIGNON
```

- **1952 Programming languages**
  - **High-level abstraction**
  - Various designs explored

1958
ALGOL



1972
C



1991
Python

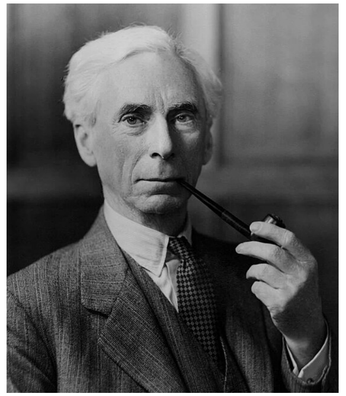
1995
Java

2009
Go

History of Types

History of Types

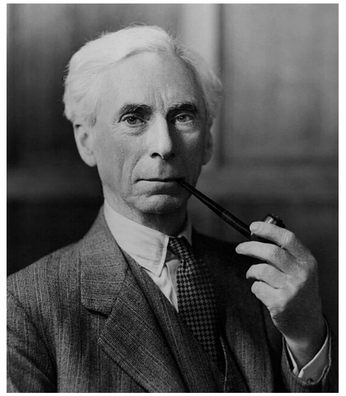
- **1903 Russel's work on types for logic**
  - To avoid **Russel's paradox** $\{S \mid S \notin S\}$



Bertrand Russel

History of Types

- **1903 Russel's work on types for logic**
  - To avoid **Russel's paradox** $\{S \mid S \notin S\}$
- **1940 Church's simply typed lambda calculus**
  - Types for a formal model of **computation**

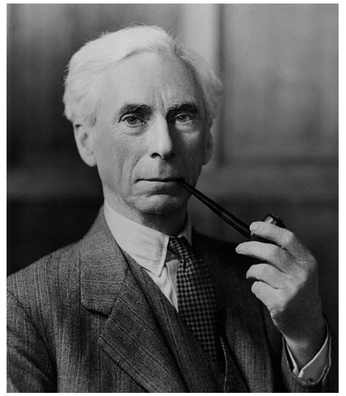


Bertrand Russel

Alonzo Church

History of Types

- **1903 Russel's work on types for logic**
  - To avoid **Russel's paradox** $\{S \mid S \notin S\}$
- **1940 Church's simply typed lambda calculus**
  - Types for a formal model of **computation**
- **1958 Types for programming languages**
  - To **prevent bugs** in software



Bertrand Russel

Alonzo Church

1. *Type declarations*

Type declarations serve to declare certain variables, or functions, to represent quantities of a given class, such as the class of integers or class of Boolean values.

Form: $\Delta \sim$ *type* (I, I, ⏦, I, I[ ], ⏦, I[,], ⏦, I[,,], ⏦) where *type* is a symbolic representative of some *type* declarator such as *integer* or *boolean*, and the I are identifiers. Throughout the program, the variables, or functions named by the identifiers I, are constrained to refer only to quantities of the type indicated by the declarator. On the other hand, all variables, or functions which are to represent other than arbitrary real numbers must be so declared.

Algol 58 Report, CACM

Formal Verification

Formal Verification

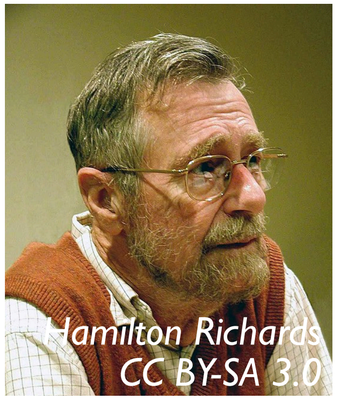
- **Prove that the software satisfies the specifications**
  - Rigorously eradicate software bugs
  - Vital for software in critical domains
    - Aerospace, automobile, finance, security, …

Formal Verification

- **Prove that the software satisfies the specifications**
  - Rigorously eradicate software bugs
  - Vital for software in critical domains
    - Aerospace, automobile, finance, security, …

- **Program logics, esp. Hoare Logic ’69**
  - Dijkstra’s weakest precondition calculus ’75
  - **Mathematical logic at work**

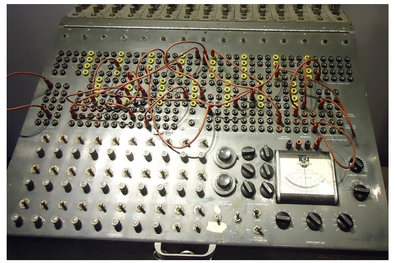
Tony Hoare



Edsger Dijkstra

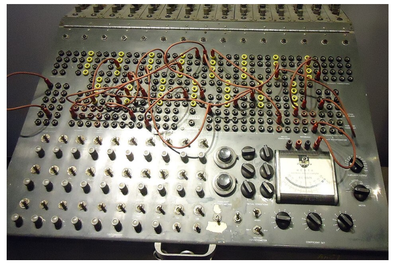
Two Big Paradigms

Two Big Paradigms



Machines

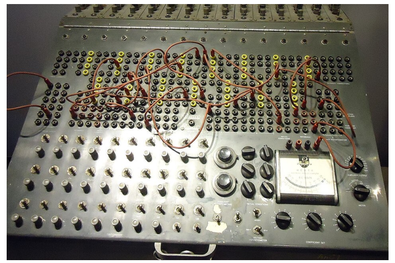
Two Big Paradigms



Machines

Humans

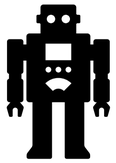
Two Big Paradigms



Machines

Humans

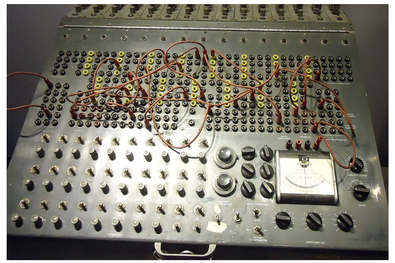
Imperative



Direct control over physical computation

- ✔ *Better performance*
- ✔ *More flexibility*

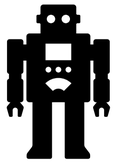
Two Big Paradigms



Machines

Humans

Imperative



Direct control over physical computation

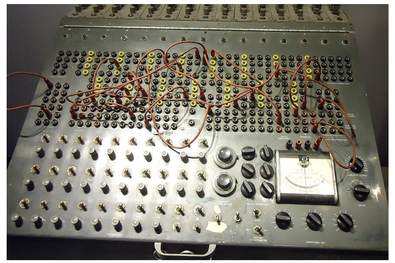
- ✔ *Better performance*
- ✔ *More flexibility*

Functional

High-level abstraction of compuation

- ✔ *Greater safety*
- ✔ *Easier reasoning*

Two Big Paradigms

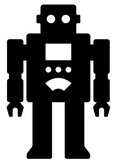


Machines

?

Humans

Imperative



Direct control over physical computation

- ✔ *Better performance*
- ✔ *More flexibility*

Functional

High-level abstraction of compuation

- ✔ *Greater safety*
- ✔ *Easier reasoning*

Rust

The Rust Language

The Rust Language

Rust

A language empowering everyone
to build reliable and efficient software.

GET STARTED

Version 1.83.0

Why Rust?

Performance

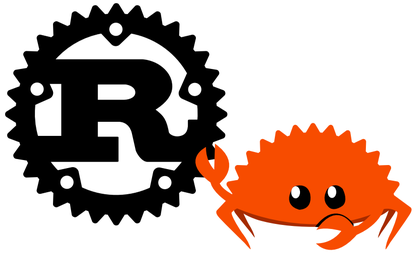
Rust is blazingly fast and memory-efficient: with no runtime or garbage collector, it can power performance-critical services, run on embedded devices, and easily integrate with other languages.

Reliability

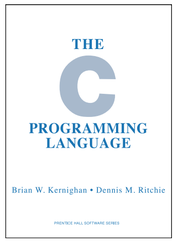
Rust's rich type system and ownership model guarantee memory-safety and thread-safety — enabling you to eliminate many classes of bugs at compile-time.

Productivity

Rust has great documentation, a friendly compiler with useful error messages, and top-notch tooling — an integrated package manager and build tool, smart multi-editor support with auto-completion and type inspections, an auto-formatter, and more.



1972 **C**



1985 **C++**

2015 **Rust**

The Rust Language

Rust

A language empowering everyone
to build reliable and efficient software.

GET STARTED

Version 1.83.0

Why Rust?

Performance

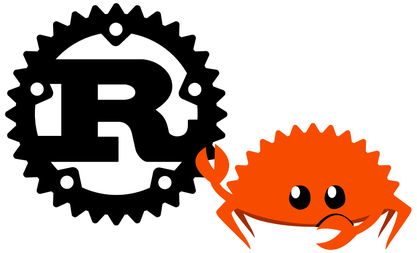
Rust is blazingly fast and memory-efficient: with no runtime or garbage collector, it can power performance-critical services, run on embedded devices, and easily integrate with other languages.

Reliability

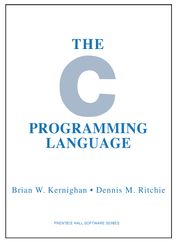
Rust's rich type system and ownership model guarantee memory-safety and thread-safety — enabling you to eliminate many classes of bugs at compile-time.

Productivity

Rust has great documentation, a friendly compiler with useful error messages, and top-notch tooling — an integrated package manager and build tool, smart multi-editor support with auto-completion and type inspections, an auto-formatter, and more.



1972 **C**



1985 **C++**

2015 **Rust**

- Rust is imperative but more functional

The Rust Language

Rust

A language empowering everyone
to build reliable and efficient software.

GET STARTED

Version 1.83.0

Why Rust?

Performance

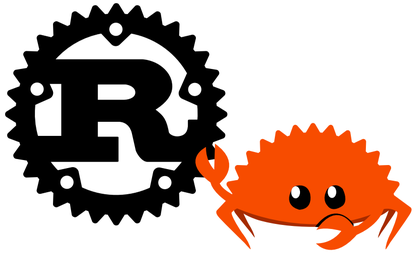
Rust is blazingly fast and memory-efficient: with no runtime or garbage collector, it can power performance-critical services, run on embedded devices, and easily integrate with other languages.

Reliability

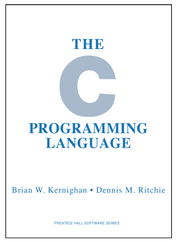
Rust's rich type system and ownership model guarantee memory-safety and thread-safety — enabling you to eliminate many classes of bugs at compile-time.

Productivity

Rust has great documentation, a friendly compiler with useful error messages, and top-notch tooling — an integrated package manager and build tool, smart multi-editor support with auto-completion and type inspections, an auto-formatter, and more.



1972 **C**



1985 **C++**

2015 **Rust**

- Rust is imperative but more functional
  - Imperative — Low-level memory & thread controls

The Rust Language

Rust

A language empowering everyone
to build reliable and efficient software.

GET STARTED

Version 1.83.0

Why Rust?

Performance

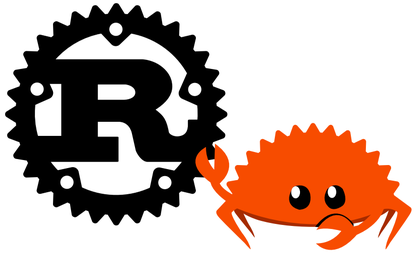
Rust is blazingly fast and memory-efficient: with no runtime or garbage collector, it can power performance-critical services, run on embedded devices, and easily integrate with other languages.

Reliability

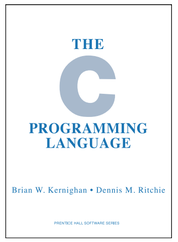
Rust's rich type system and ownership model guarantee memory-safety and thread-safety — enabling you to eliminate many classes of bugs at compile-time.

Productivity

Rust has great documentation, a friendly compiler with useful error messages, and top-notch tooling — an integrated package manager and build tool, smart multi-editor support with auto-completion and type inspections, an auto-formatter, and more.



1972 **C**



1985 **C++**

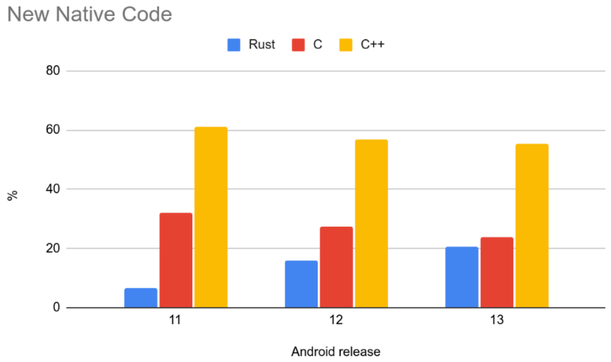
2015 **Rust**

- Rust is imperative but more functional
  - Imperative — Low-level memory & thread controls
  - More functional — Ownership types to tame state mutation

Rust in the Real World

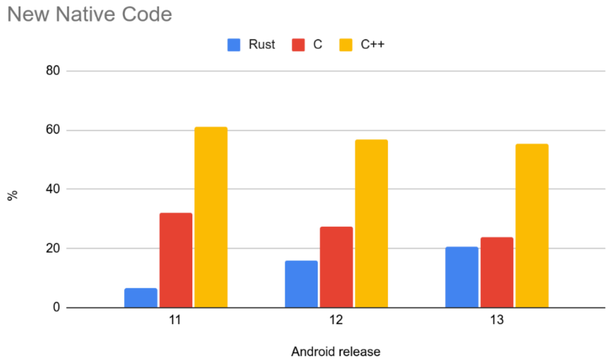
Rust in the Real World

- Google's Android OS
  - Rust reduced vulnerabilities



Rust in the Real World

- Google's Android OS
  - Rust **reduced vulnerabilities**

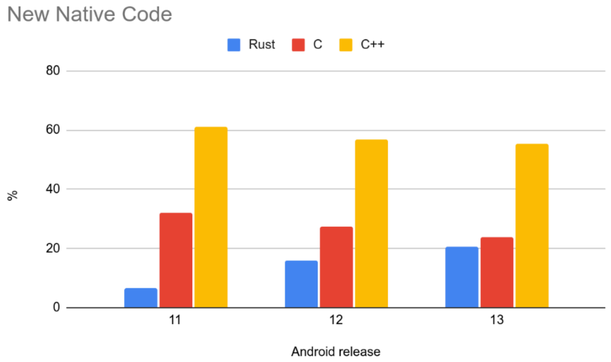


- Mozilla's Firefox web browser
  - Rust was born from and raised by **Mozilla**

Mozilla

Rust in the Real World

- **Google's Android OS**
  - Rust **reduced vulnerabilities**



- **Mozilla's Firefox web browser**
  - Rust was born from and raised by **Mozilla**

Mozilla

- **Security & performance**
  - **VMs: AWS**'s Firecracker, Google's crosvm
  - **Language engines**: Deno, Wasmer

Days before Rust

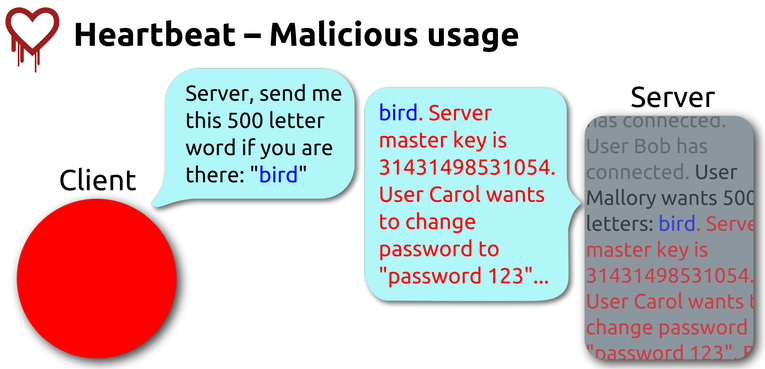
Days before Rust

Heartbleed

'12 Introduced
'14 Disclosed & fixed

Severe bug in OpenSSL, a widely used library for secure communications

Memory corruption caused by C

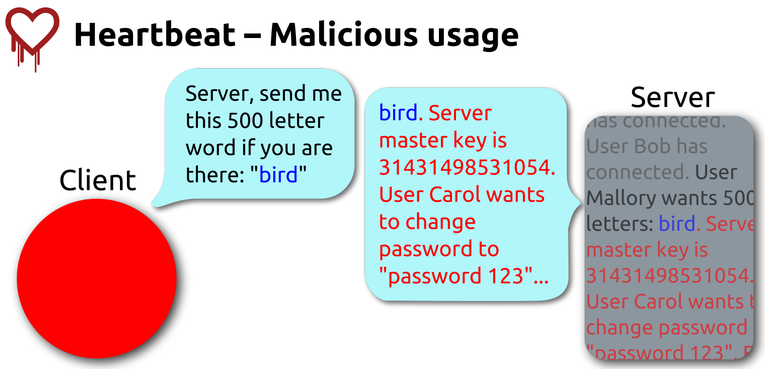


Days before Rust

Heartbleed

'12 Introduced
'14 Disclosed & fixed

*Severe bug in OpenSSL, a widely used library for **secure communications***
***Memory corruption** caused by C*



- **Severe vulnerabilities due to memory corruption**
  - Languages like **C/C++** are **not memory-safe!**
  - ~70% of **zero-day attacks** -'19 stem from **memory corruption** — Google Project Zero

CVE	Vendor	Product	Type
CVE-2019-7286	Apple	iOS	Memory Corruption
CVE-2019-7287	Apple	iOS	Memory Corruption
CVE-2019-0676	Microsoft	Internet Explorer	Information Leak
CVE-2019-5786	Google	Chrome	Memory Corruption
CVE-2019-0808	Microsoft	Windows	Memory Corruption
CVE-2019-0797	Microsoft	Windows	

Aliasing AND Mutability is Dangerous

- **Aliased** mutable state is the core source of bugs

Aliasing AND Mutability is Dangerous

- **Aliased** mutable state is the core source of bugs

Example A **dangling** pointer caused by a **data race**

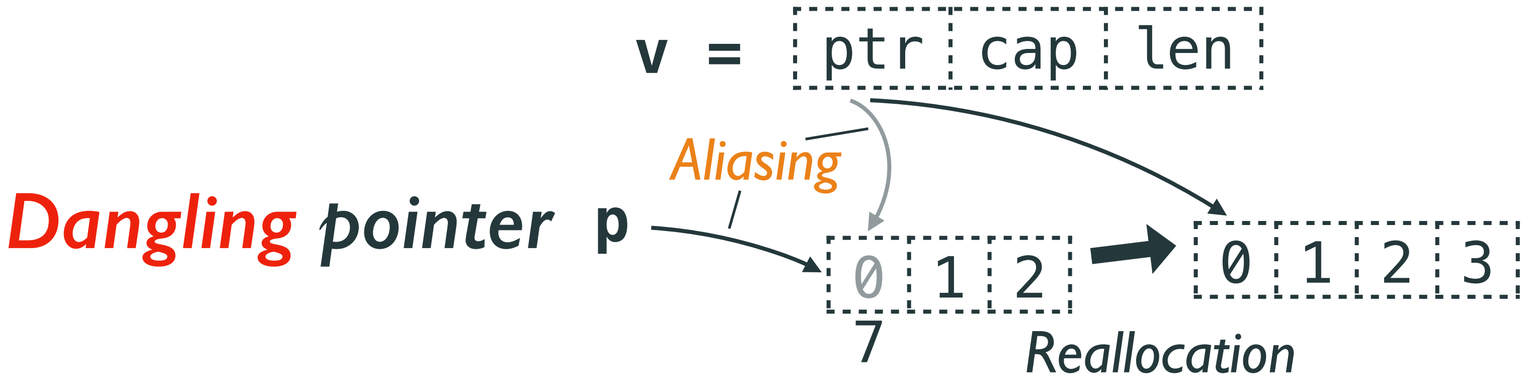
```
vector<int> v { 0, 1, 2 };  int *p = &v[0];
v.push_back(3);   *p = 7;  // Data race!
printf("%d\n", v[0]); // Prints 0, not 7
```

Aliasing AND Mutability is Dangerous

- **Aliased** mutable state is the core source of bugs

Example A **dangling** pointer caused by a **data race**

```
vector<int> v { 0, 1, 2 };  int *p = &v[0];
v.push_back(3);   *p = 7;  // Data race!
printf("%d\n", v[0]); // Prints 0, not 7
```



Rust Bans Aliasing AND Mutability

- Rust's ownership types ban "Aliasing AND Mutability"

Rust Bans Aliasing AND Mutability

- Rust's ownership types ban "Aliasing AND Mutability"

Example

```
let mut v = vec![0, 1, 2];  let p = &mut v[0];
v.push(3);    *p = 7;  // OWNERSHIP ERROR
println!("{}", v[0]);
```

Rust Bans Aliasing AND Mutability

- Rust's ownership types ban "Aliasing AND Mutability"

Example

```
let mut v = vec![0, 1, 2];  let p = &mut v[0];
v.push(3);    *p = 7;  // OWNERSHIP ERROR
println!("{}", v[0]);
```

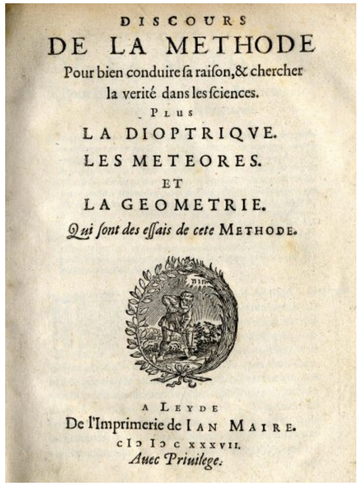
Bug detected!

```
error[E0499]: cannot borrow `v` as mutable more than once at a time
  | ...;  let p = &mut v[0];
  |                    - first mutable borrow occurs here
  | v.push(3);    *p = 7;  // Data race!
  | ^            ------ first borrow later used here
  | second mutable borrow occurs here
```

Science behind Rust

Divide the Difficulties

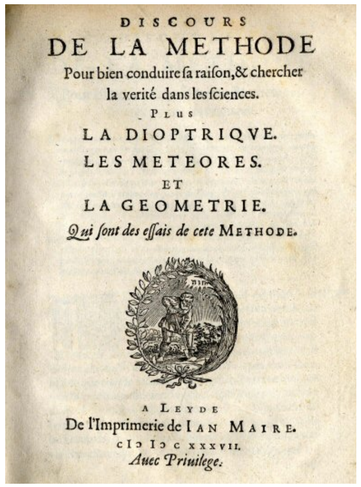
Divide the Difficulties


DISCOURS
DE LA METHODE
Pour bien conduire sa raison, & chercher
la verité dans les sciences.
PLUS
LA DIOPTRIQVE.
LES METEORES.
ET
LA GEOMETRIE.
Qui sont des essais de cette METHODE.
A LEYDE
De l'Imprimerie de IAN MAIRE.
cIↃ IↃ C XXXVII.
Auec Priuilege.

*The second: to **divide** each of the **difficulties** under examination into as **many parts** as possible, and as might be necessary for its **adequate solution**.*

Discourse on the Method, René Descartes

Divide the Difficulties


DISCOURS
DE LA METHODE
Pour bien conduire sa raison, & chercher la verité dans les sciences.
PLUS
LA DIOPTRIQVE.
LES METEORES.
ET
LA GEOMETRIE.
Qui sont des essais de cette METHODE.
A LEYDE
De l'Imprimerie de IAN MAIRE.
cIↃ IↃ C XXXVII.
Auec Priuilege.

*The second: to **divide** each of the **difficulties** under examination into as **many parts** as possible, and as might be necessary for its **adequate solution**.*

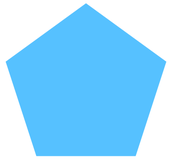
Discourse on the Method, René Descartes

- **To overcome the difficulties, divide them**
  - **Modular & Composable → Scalable**

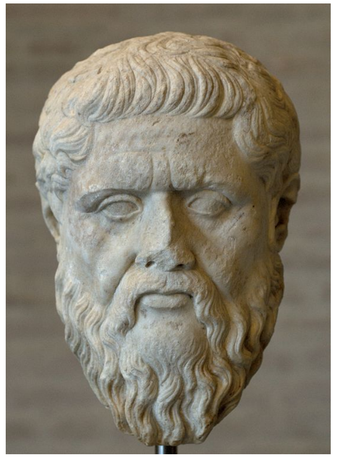
Human Ideals vs Physical Computation

Human Ideals vs Physical Computation

- Ideally, everything is just persistent
  - Metaphysics of Platonic Forms
  - Usual mathematics

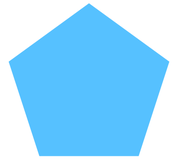


$1 + 2 = 3$

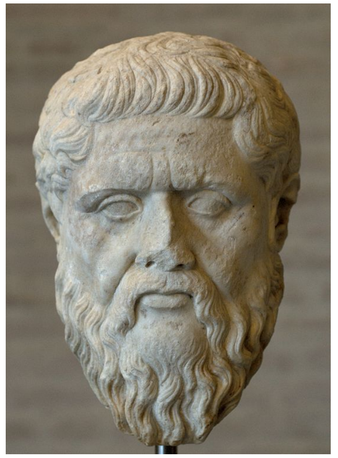


Human Ideals vs Physical Computation

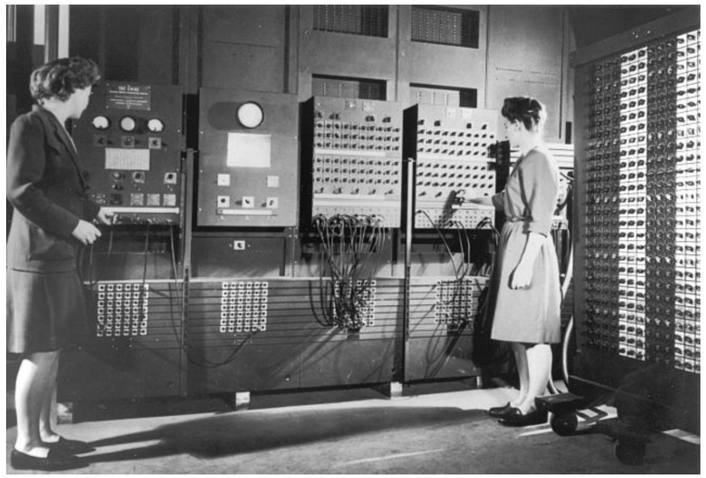
- Ideally, everything is just persistent
  - Metaphysics of Platonic Forms
  - Usual mathematics



$1 + 2 = 3$



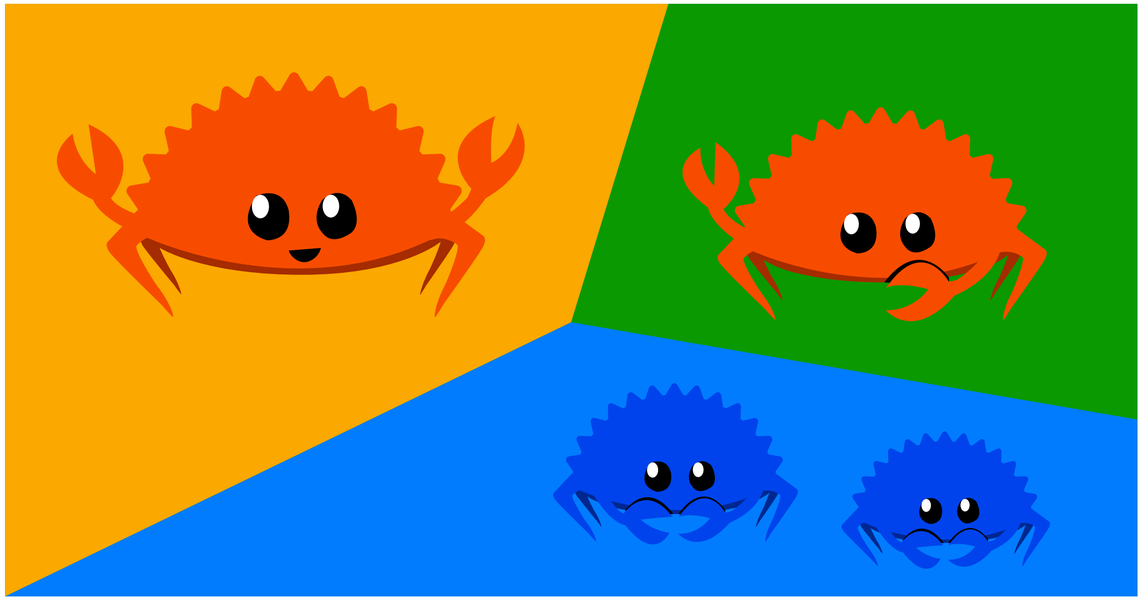
- Physical computation breaks things
  - Mutable state — Memory, environment, etc.
  - Naive reasoning can break by state update



Rust’s Ownership Types

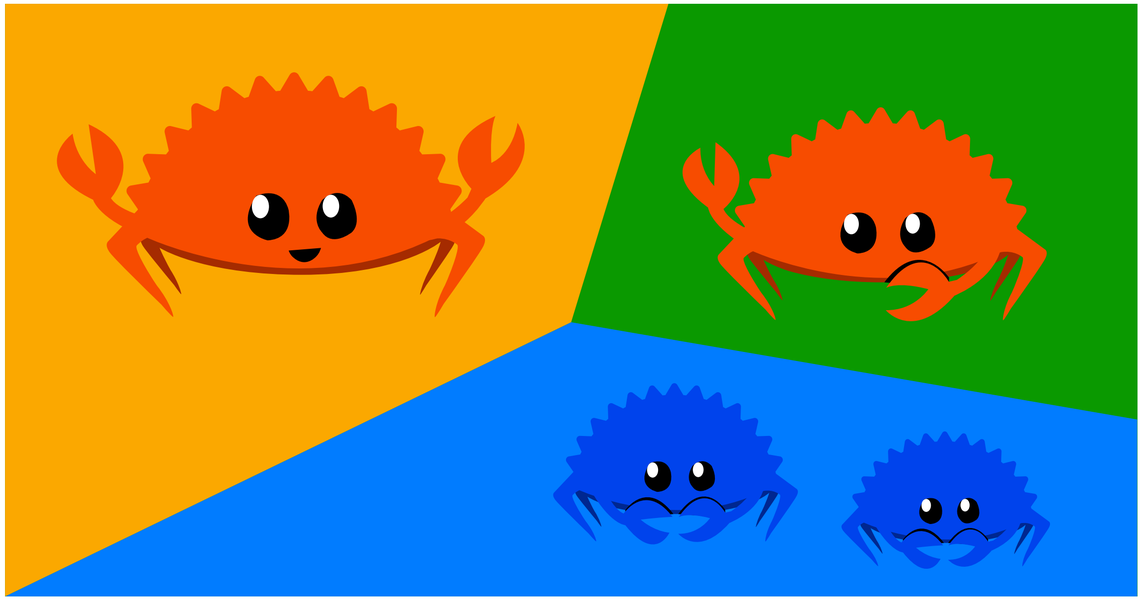
Rust's Ownership Types

Separation by Ownership



Rust's Ownership Types

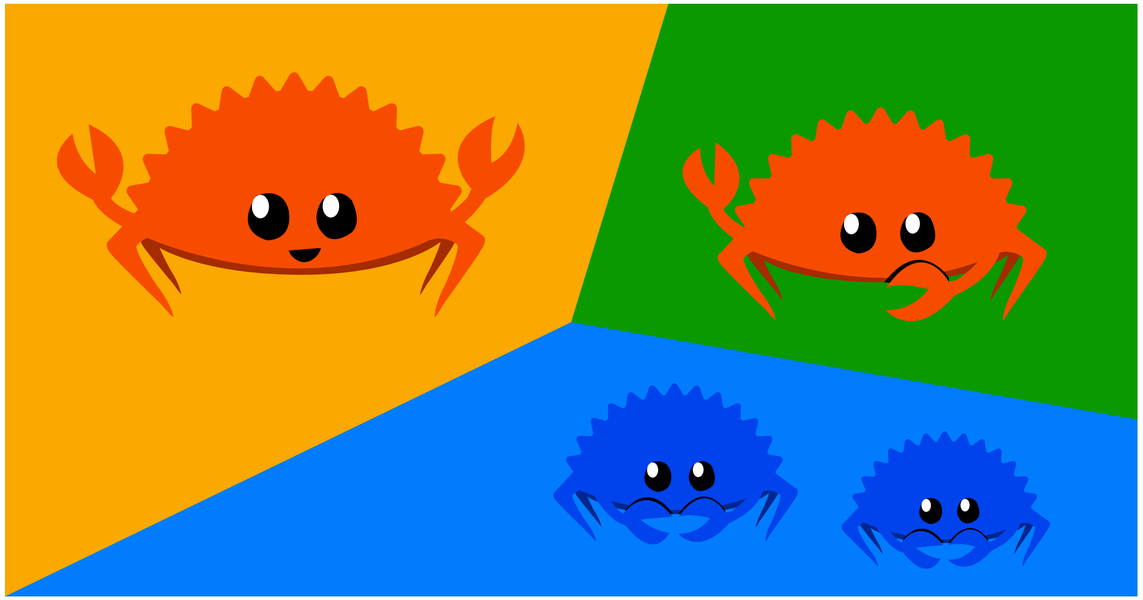
Separation by Ownership



XOR

Rust's Ownership Types

Separation by Ownership



XOR

→ ***No dangerous interference between computations***

From Logic to Rust

From Logic to Rust

- Linear logic inspired Rust's ownership types

From Logic to Rust

- Linear logic inspired Rust's ownership types

Linear logic

Girard 1987

$$\frac{\vdash A, C \quad \vdash B, D}{\vdash A \otimes B, C, D}\otimes, \qquad \frac{\vdash A, B, C}{\vdash A \parr B, C}\parr$$

From Logic to Rust

- Linear logic inspired Rust's ownership types

Linear logic

Girard 1987

$$\frac{\vdash A, C \quad \vdash B, D}{\vdash A \otimes B, C, D}\otimes, \qquad \frac{\vdash A, B, C}{\vdash A \parr B, C}\parr$$

Linear types

Wadler 1990

Region types

Tofte & Talpin 1994

Ownership types

Clarke+ 1998

From Logic to Rust

- Linear logic inspired Rust's ownership types

Linear logic

Girard 1987

$$\frac{\vdash A, C \quad \vdash B, D}{\vdash A \otimes B, C, D}\otimes, \qquad \frac{\vdash A, B, C}{\vdash A \parr B, C}\parr$$

Linear types

Wadler 1990

Region types

Tofte & Talpin 1994

Ownership types

Clarke+ 1998

Cyclone

Grossman+ 2002

Borrows

From Logic to Rust

- Linear logic inspired Rust's ownership types

Linear logic

Girard 1987

$$\frac{\vdash A, C \quad \vdash B, D}{\vdash A \otimes B, C, D}\otimes, \qquad \frac{\vdash A, B, C}{\vdash A \parr B, C}\parr$$

Linear types

Wadler 1990

Region types

Tofte & Talpin 1994

Ownership types

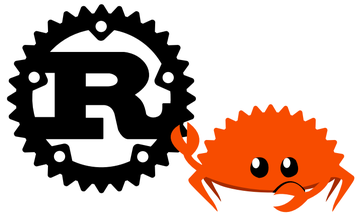
Clarke+ 1998

Cyclone

Grossman+ 2002

Borrows

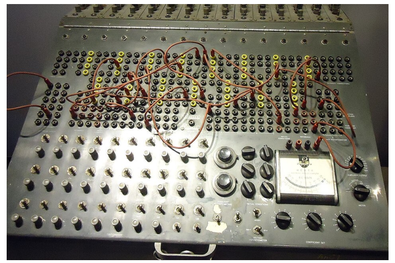
Rust



Matsakis+ 2015

My Research

Big Goal of Software Science

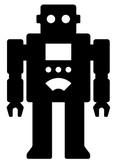


Machines

?

Humans

Imperative



Direct control over physical computation

- ✔ *Better performance*
- ✔ *More flexibility*

Functional

High-level abstraction of compuation

- ✔ *Greater safety*
- ✔ *Easier reasoning*

My Work — Unify Imperative & Functional

My Work — Unify Imperative & Functional

- **RustHorn** ESOP ’20 / TOPLAS ’21
  - **Rust** can be modeled as **functional** by **prophecies**

My Work — Unify Imperative & Functional

- ✦ **RustHorn** ESOP ’20 / TOPLAS ’21
  - ▸ **Rust** can be modeled as **functional** by **prophecies**

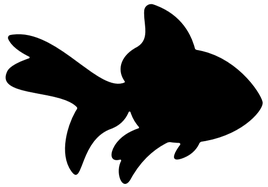
- ✦ **RustHornBelt** PLDI ’22
  - ▸ Proving **RustHorn** sound **modularly** in **logic**

My Work — Unify Imperative & Functional

- ✦ **RustHorn** ESOP ’20 / TOPLAS ’21
  - ▸ **Rust** can be modeled as **functional** by **prophecies**

- ✦ **RustHornBelt** PLDI ’22
  - ▸ Proving **RustHorn** sound **modularly** in **logic**

- ✦ **Pure Borrow** PLDI ’26
  - ▸ **Linear Haskell** + **Rust-style borrows**, with **purity**

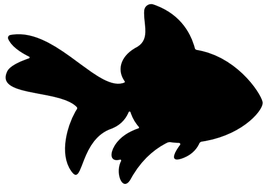


My Work — Unify Imperative & Functional

- **RustHorn** ESOP ’20 / TOPLAS ’21
  - **Rust** can be modeled as **functional** by **prophecies**

- **RustHornBelt** PLDI ’22
  - Proving **RustHorn** sound **modularly** in **logic**

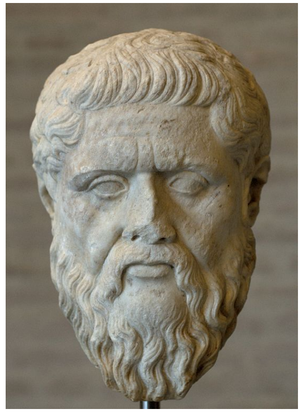
- **Pure Borrow** PLDI ’26
  - **Linear Haskell** + **Rust-style borrows**, with **purity**



Basic Idea: Rust into Functional Models

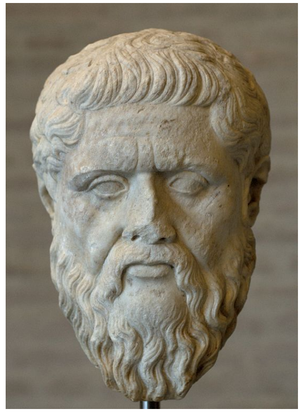
Basic Idea: Rust into Functional Models

- ✦ **Turn Rust programs into functional models**
  - ▸ Leveraging **Rust's ownership types**
  - ▸ Into the mathematical world where **all is persistent**

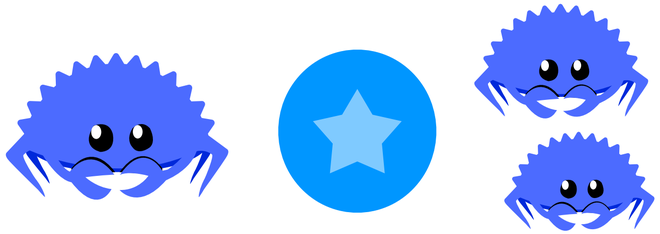


Basic Idea: Rust into Functional Models

- ✦ **Turn Rust programs into functional models**
  - ▸ Leveraging **Rust's ownership types**
  - ▸ Into the mathematical world where **all is persistent**



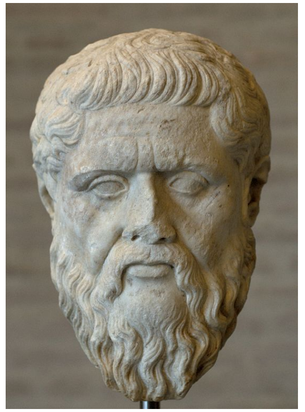
Aliased & Immutable



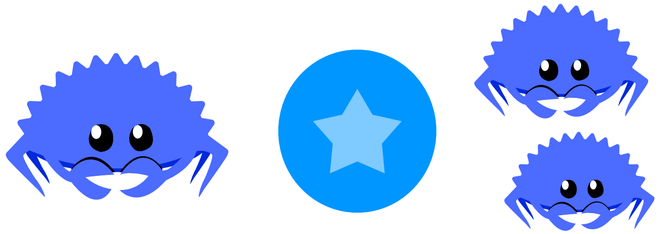
Just an immutable value

Basic Idea: Rust into Functional Models

- ✦ Turn Rust programs into functional models
  - ▸ Leveraging **Rust's ownership types**
  - ▸ Into the mathematical world where **all is persistent**

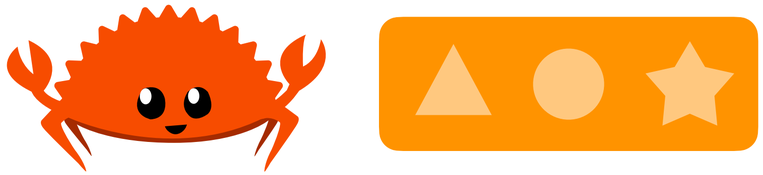


Aliased & Immutable



Just an immutable value

Fully owned



Can track the value change

Challenge: Rust's Mutable Borrows

Challenge: Rust's Mutable Borrows

Owner
T

Challenge: Rust's Mutable Borrows

Owner
T

Mutable Borrow

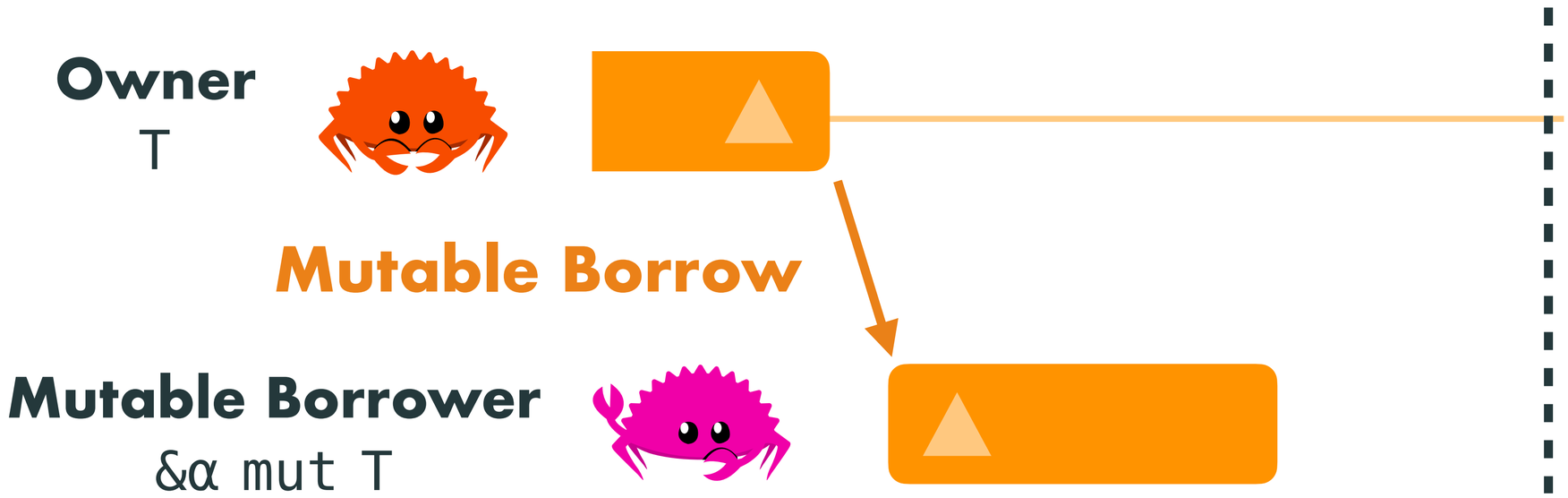
Challenge: Rust's Mutable Borrows

Owner
`T`

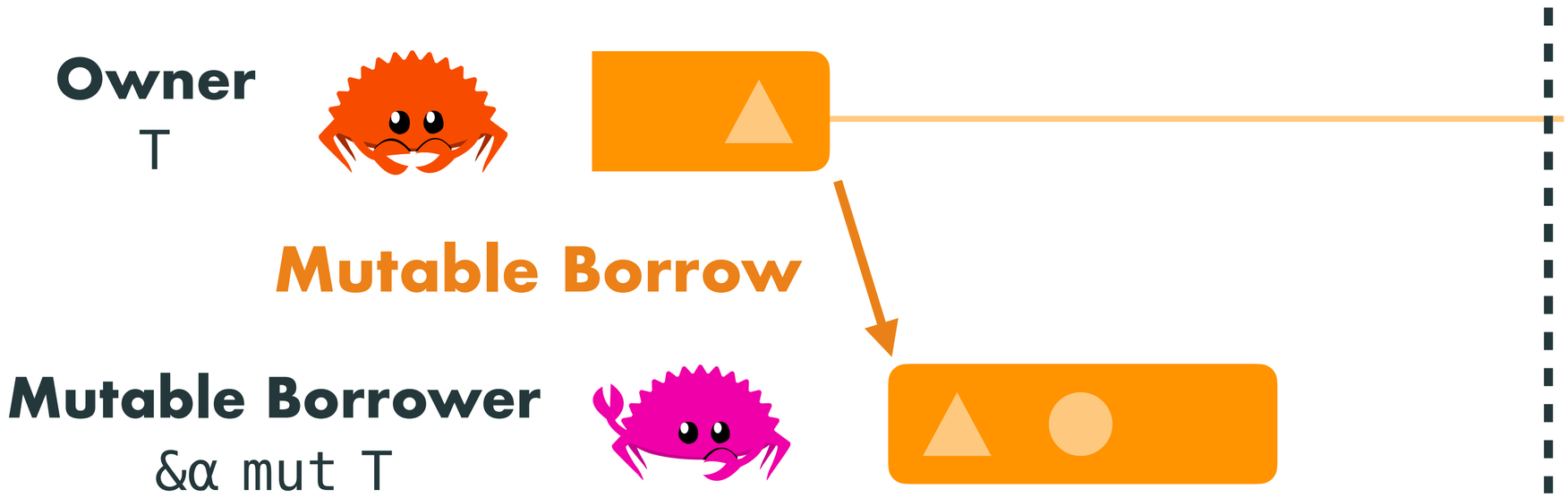
Mutable Borrow

Mutable Borrower
`&α mut T`

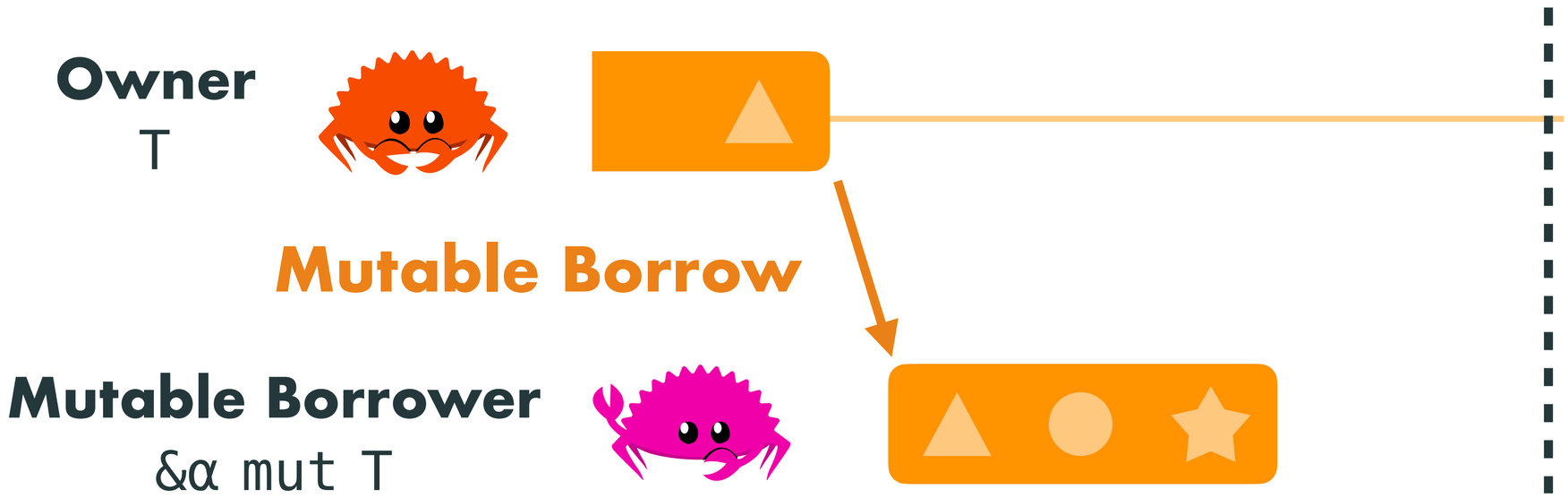
Challenge: Rust's Mutable Borrows



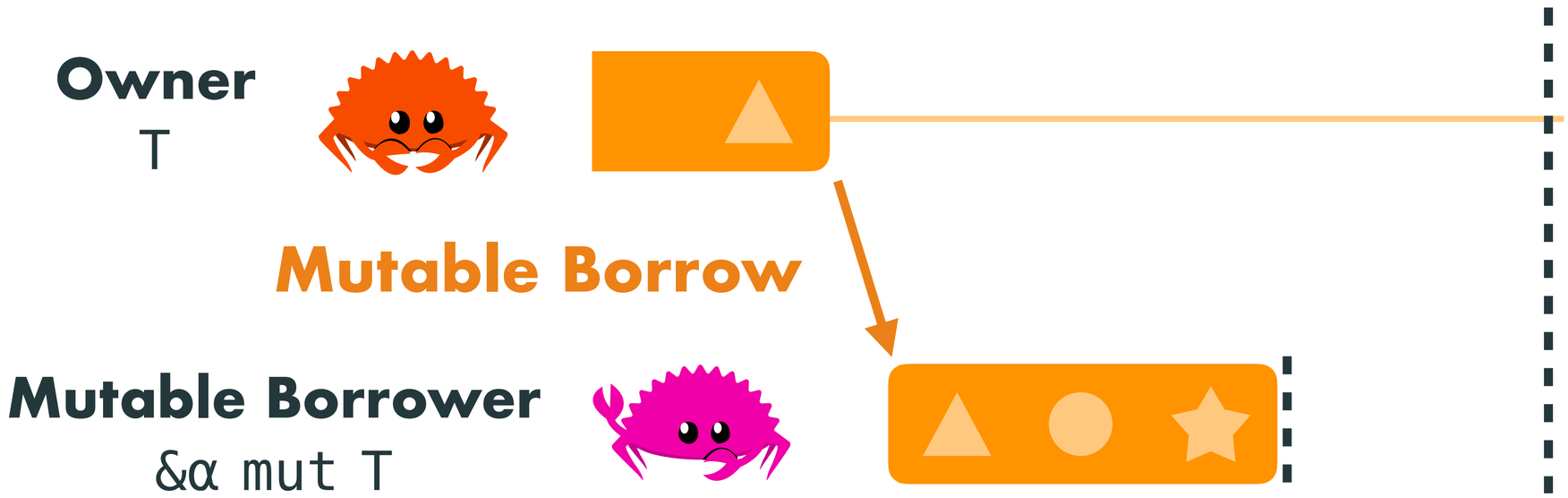
Challenge: Rust's Mutable Borrows



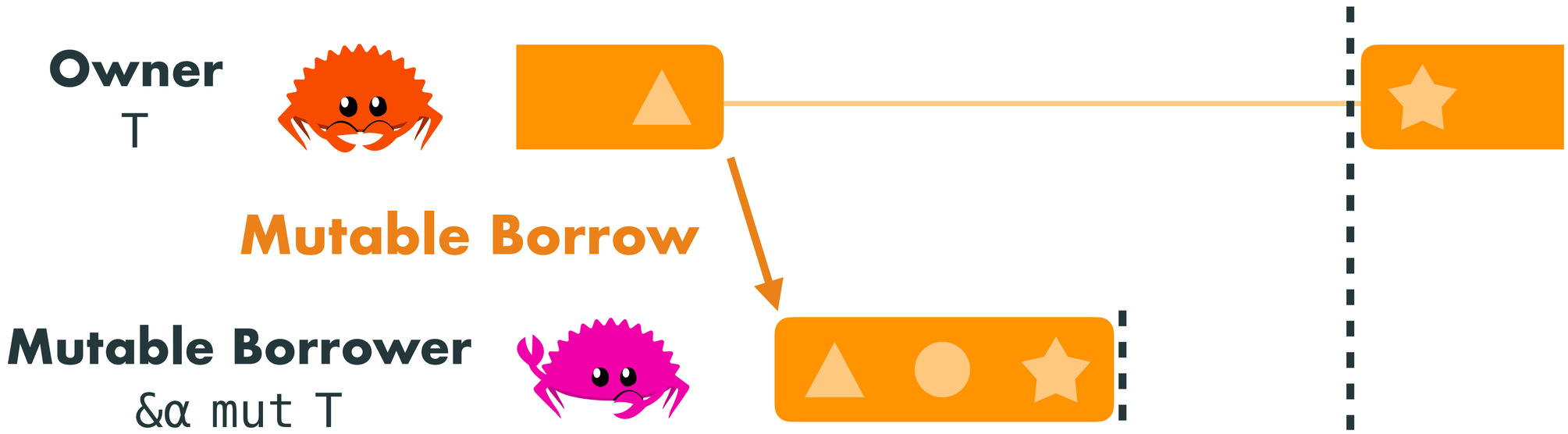
Challenge: Rust's Mutable Borrows



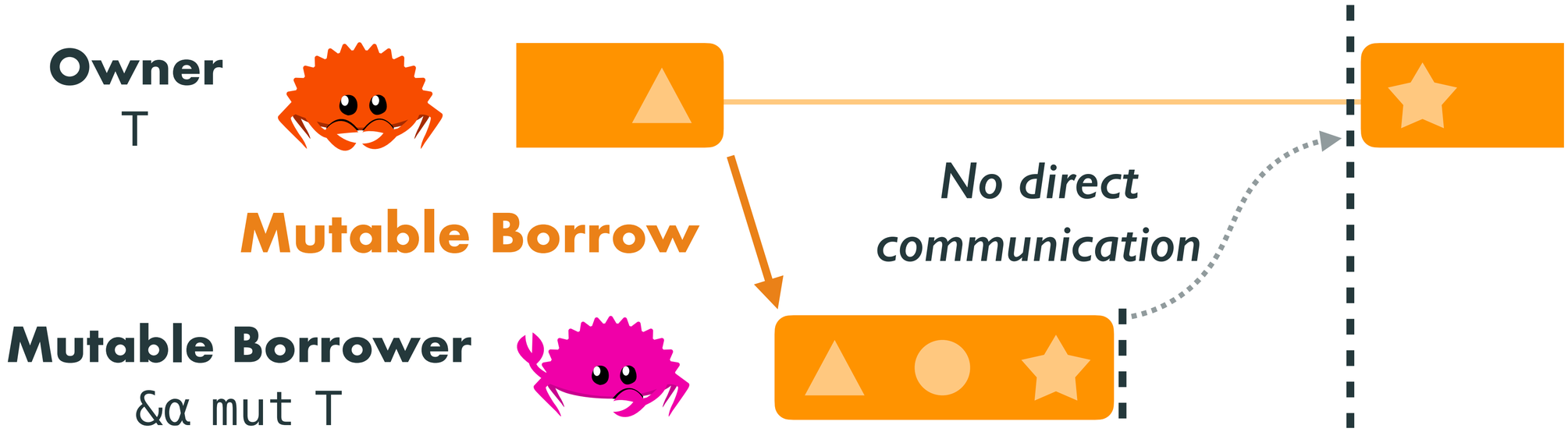
Challenge: Rust's Mutable Borrows



Challenge: Rust's Mutable Borrows



Challenge: Rust's Mutable Borrows



Challenge: Rust's Mutable Borrows

Challenge: Rust's Mutable Borrows

- ✦ **Mutable borrows are hard for functional reasoning**
  - ▸ How to "**tell**" the **lender** the **result** of the **borrower's mutation**?

Solution: My Work, RustHorn

Matsushita+
ESOP'20 / TOPLAS'21

Solution: My Work, RustHorn 

Matsushita+
ESOP'20 / TOPLAS'21

- Model mutable borrows by prophecy 

Solution: My Work, RustHorn

Matsushita+
ESOP'20 / TOPLAS'21

- **Model mutable borrows by prophecy** 
  - **Prophecy** [Abadi & Lamport '88]: Fetches info about the **future**

Solution: My Work, RustHorn

Matsushita+
ESOP'20 / TOPLAS'21

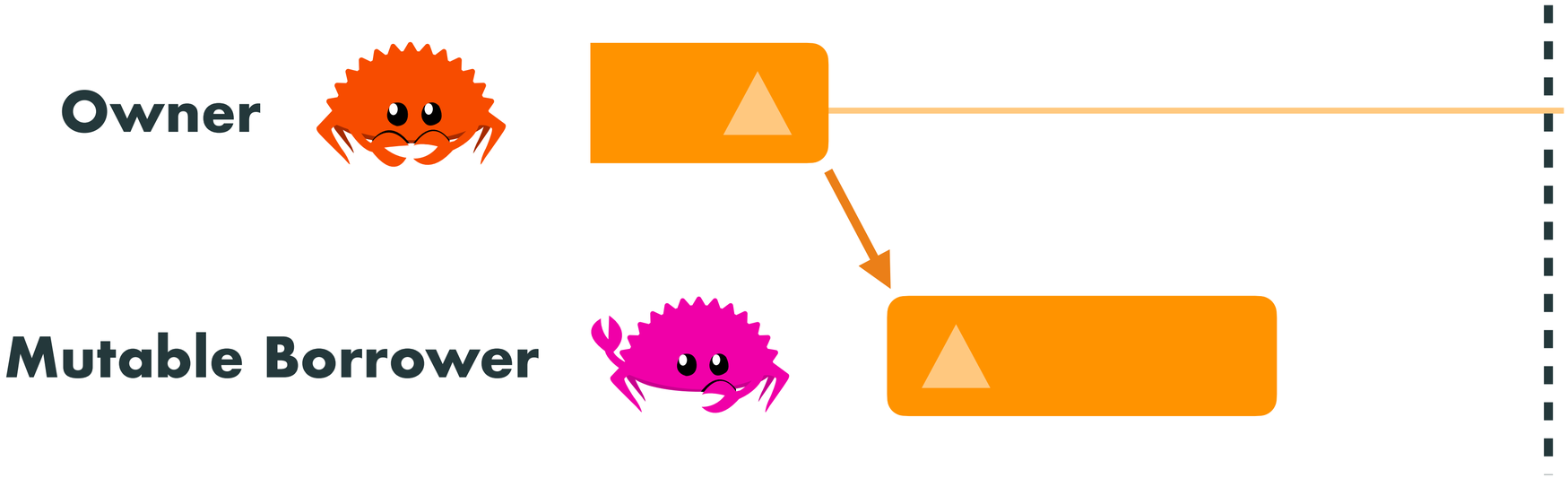
- **Model mutable borrows by prophecy** 
  - **Prophecy** [Abadi & Lamport '88]: Fetches info about the **future**
    - Here, the **result** of the **borrower's mutation**

Solution: My Work, RustHorn

Matsushita+
ESOP'20 / TOPLAS'21

- **Model mutable borrows by prophecy**

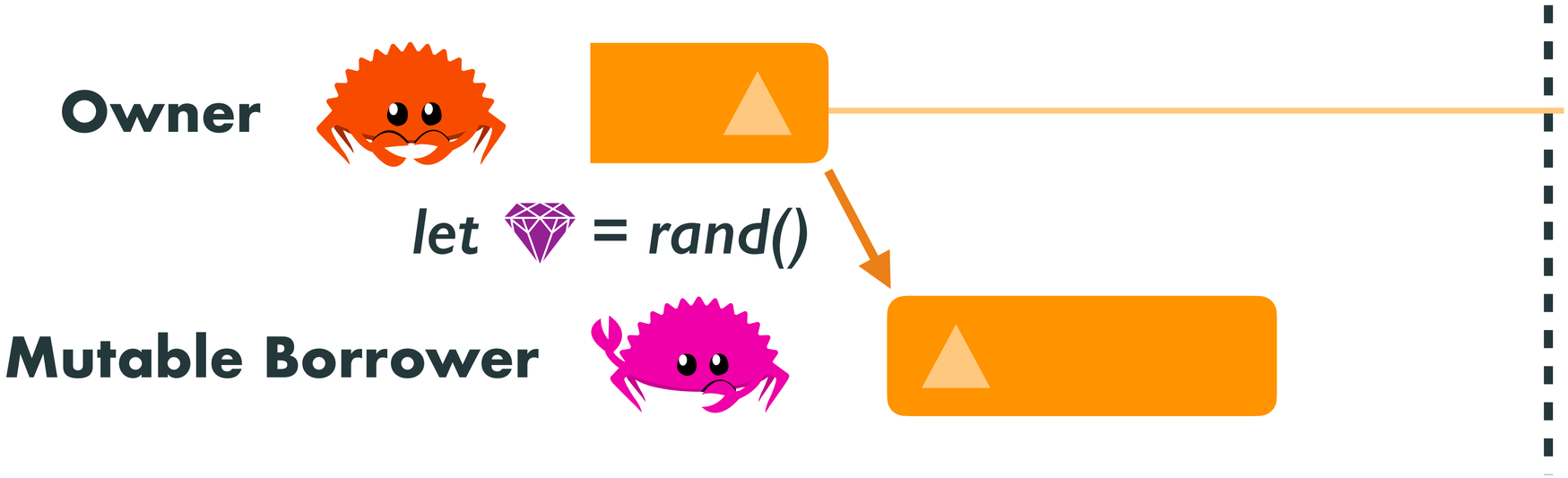
  - **Prophecy** [Abadi & Lamport '88]: Fetches info about the **future**
    - Here, the **result** of the **borrower's mutation**



Solution: My Work, RustHorn

Matsushita+
ESOP'20 / TOPLAS'21

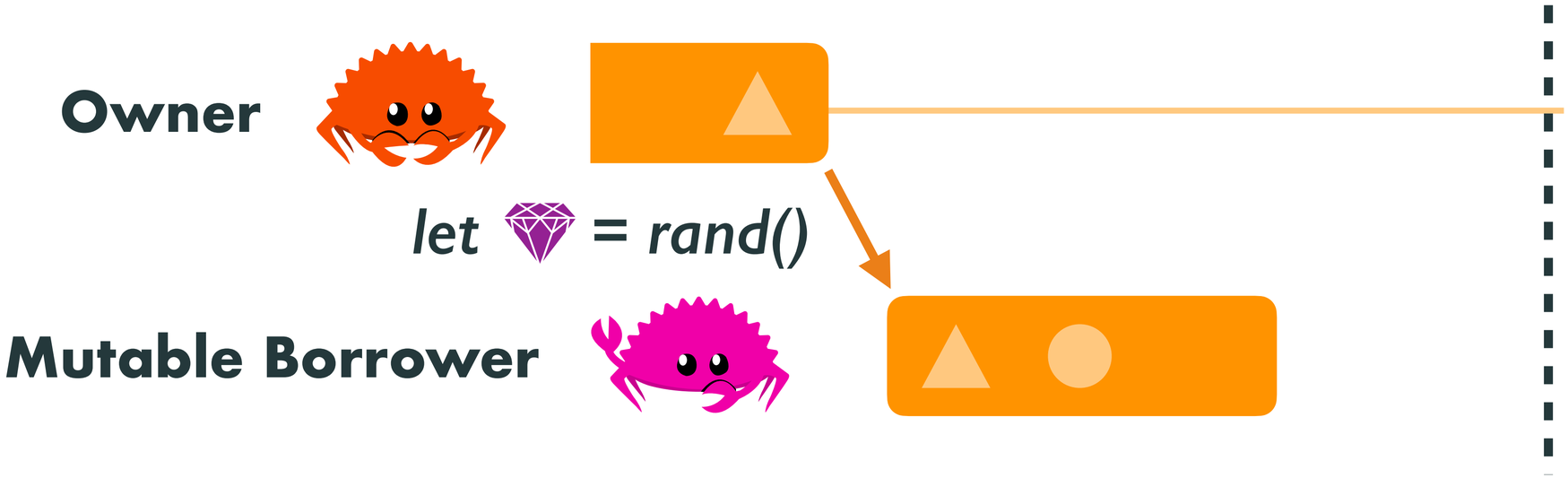
- **Model mutable borrows by prophecy** 
  - **Prophecy** [Abadi & Lamport '88]: Fetches info about the **future**
    - Here, the **result** of the **borrower's mutation**



Solution: My Work, RustHorn

Matsushita+
ESOP'20 / TOPLAS'21

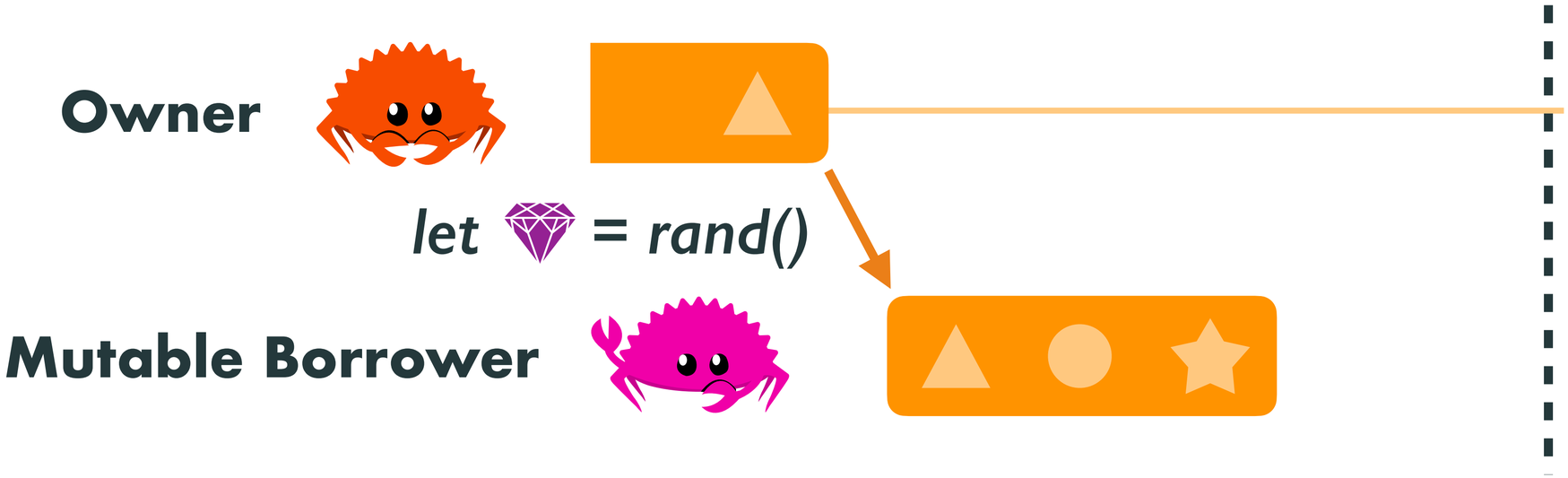
- **Model mutable borrows by prophecy** 
  - **Prophecy** [Abadi & Lamport '88]: Fetches info about the **future**
    - Here, the **result** of the **borrower's mutation**



Solution: My Work, RustHorn

Matsushita+
ESOP'20 / TOPLAS'21

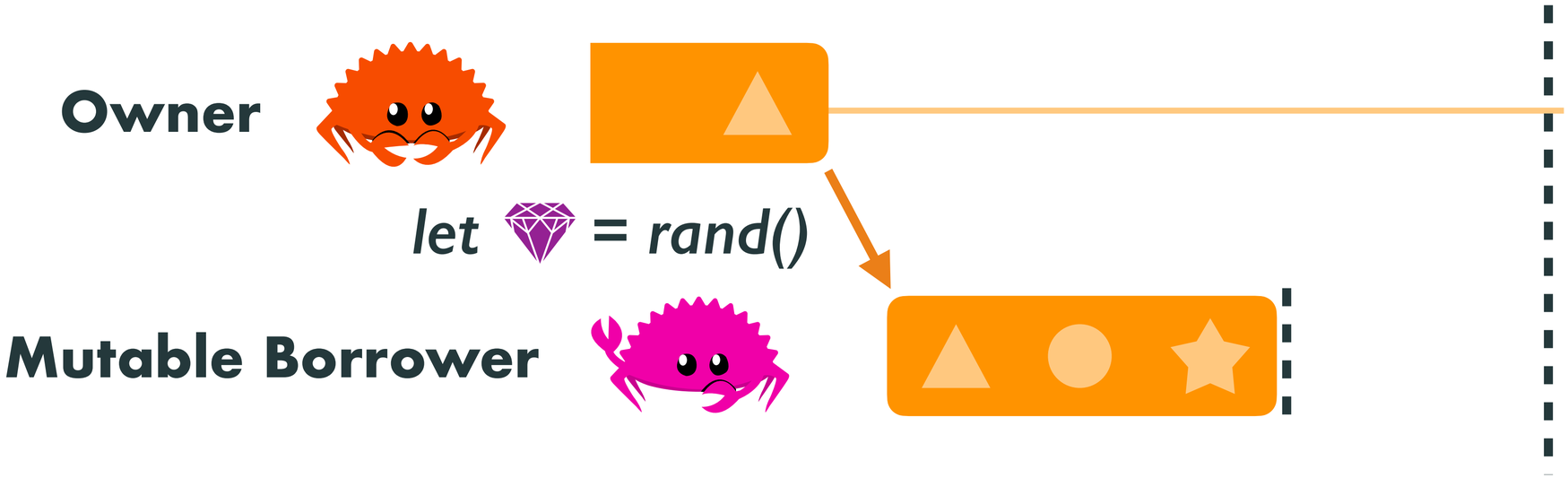
- **Model mutable borrows by prophecy** 
  - **Prophecy** [Abadi & Lamport '88]: Fetches info about the **future**
    - Here, the **result** of the **borrower's mutation**



Solution: My Work, RustHorn

Matsushita+
ESOP'20 / TOPLAS'21

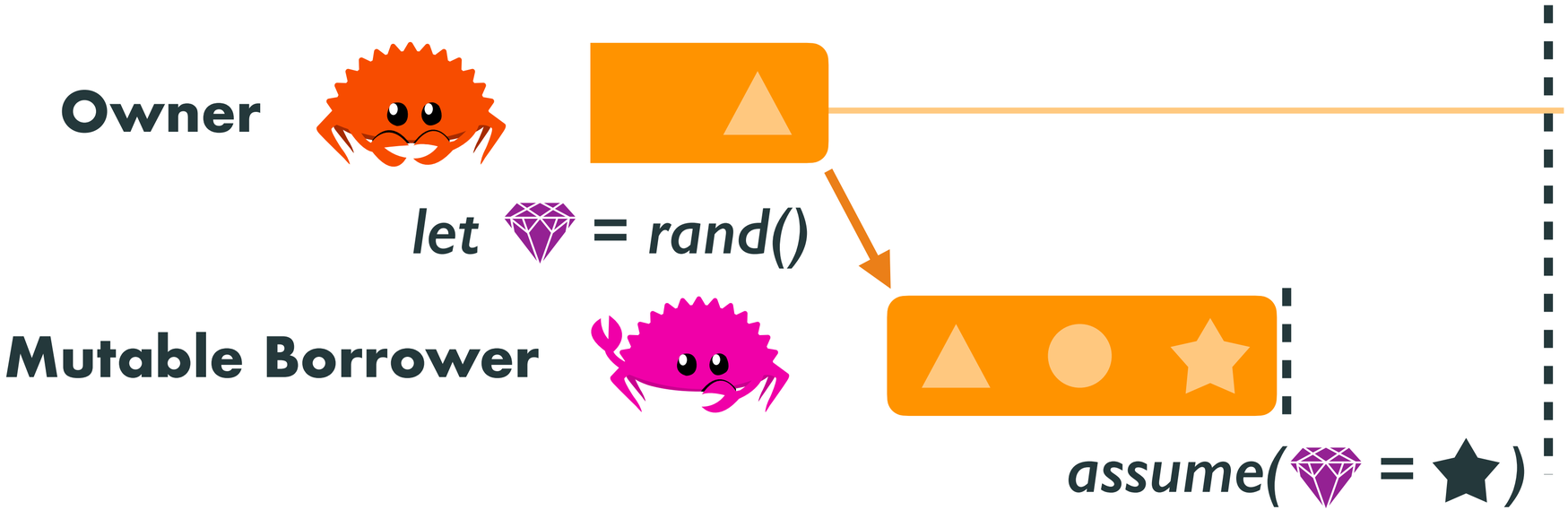
- **Model mutable borrows by prophecy** 
  - **Prophecy** [Abadi & Lamport '88]: Fetches info about the **future**
    - Here, the **result** of the **borrower's mutation**



Solution: My Work, RustHorn

Matsushita+
ESOP'20 / TOPLAS'21

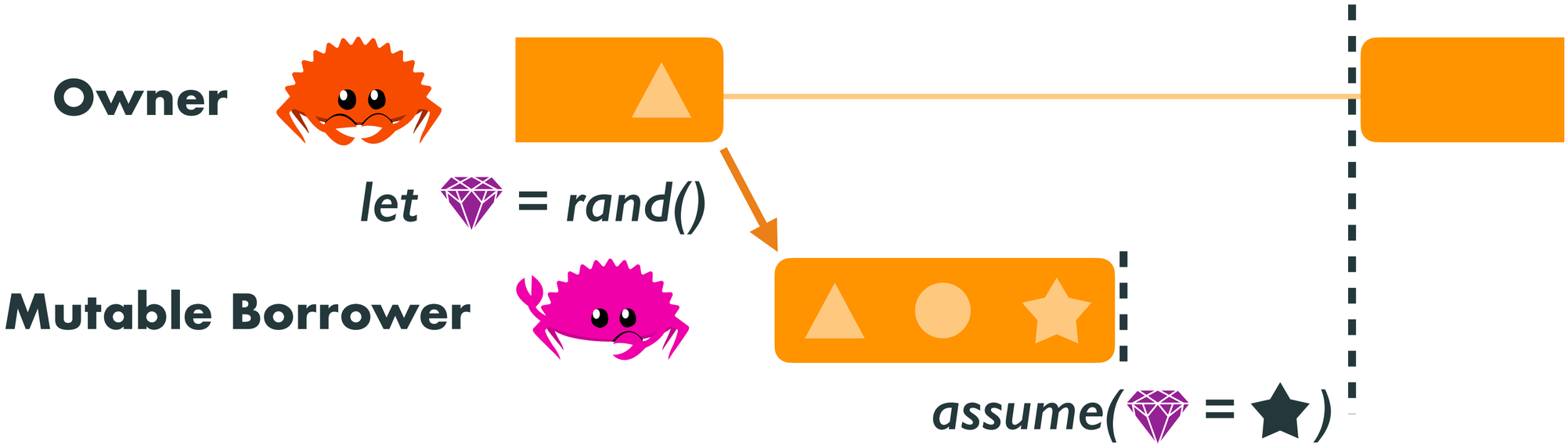
- **Model mutable borrows by prophecy** 
  - **Prophecy** [Abadi & Lamport '88]: Fetches info about the **future**
    - Here, the **result** of the **borrower's mutation**



Solution: My Work, RustHorn

Matsushita+
ESOP'20 / TOPLAS'21

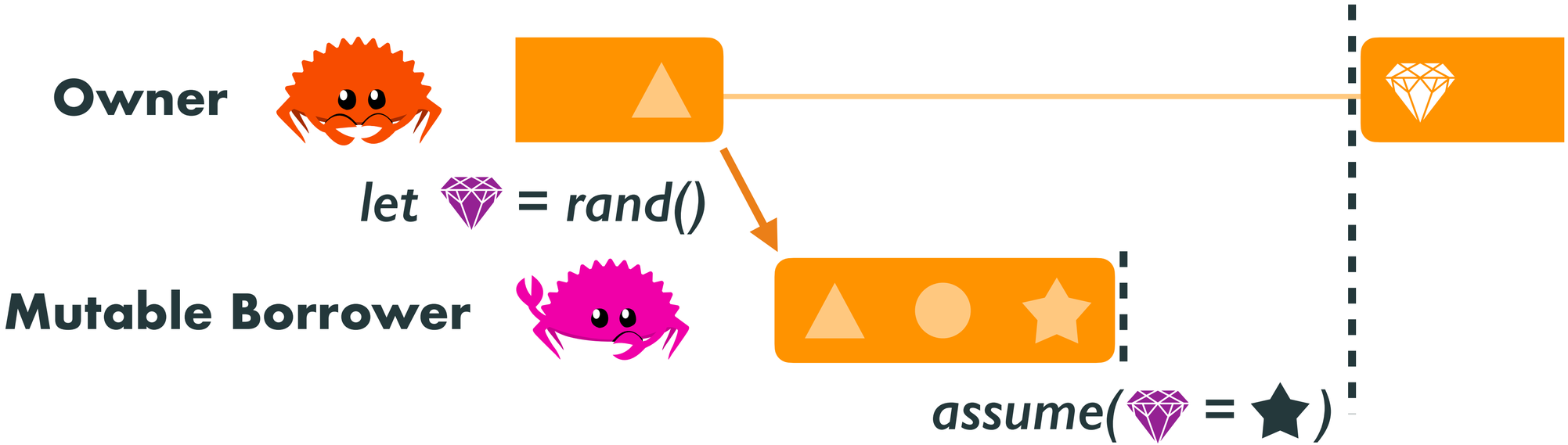
- **Model mutable borrows by prophecy** 
  - **Prophecy** [Abadi & Lamport '88]: Fetches info about the **future**
    - Here, the **result** of the **borrower's mutation**



Solution: My Work, RustHorn

Matsushita+
ESOP'20 / TOPLAS'21

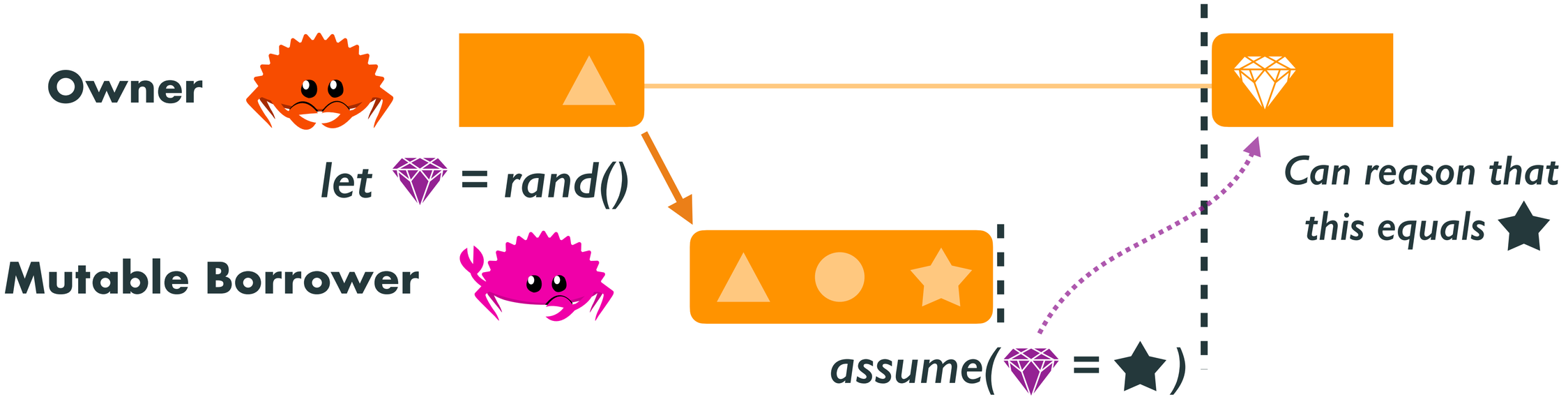
- **Model mutable borrows by prophecy**
  - **Prophecy** [Abadi & Lamport '88]: Fetches info about the **future**
    - Here, the **result** of the **borrower's mutation**



Solution: My Work, RustHorn

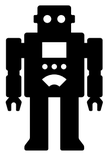
Matsushita+
ESOP'20 / TOPLAS'21

- **Model mutable borrows by prophecy** 
  - **Prophecy** [Abadi & Lamport '88]: Fetches info about the **future**
    - Here, the **result** of the **borrower's mutation**

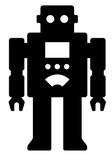


Example of RustHorn's Translation

Example of RustHorn's Translation

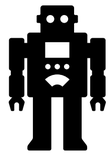
Rust 

Example of RustHorn's Translation

Rust 

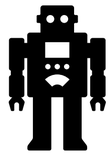
```
fn take_max<α>
    (ma: &α mut i32, mb: &α mut i32)
     -> &α mut i32 {
  if *ma >= *mb { ma } else { mb }
}

fn test(mut a: i32, mut b: i32) {
  *take_max(&mut a, &mut b) += 7;
  assert!((a - b).abs() >= 7);
}
```

Example of RustHorn's Translation

Rust 

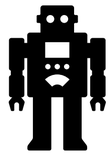
```
fn take_max<α>
    (ma: &α mut i32, mb: &α mut i32)
     -> &α mut i32 {
  if *ma >= *mb { ma } else { mb }
}

fn test(mut a: i32, mut b: i32) {
  *take_max(&mut a, &mut b) += 7;
  assert!((a - b).abs() >= 7);
}
```

Example of RustHorn's Translation

Rust   ML 

```
fn take_max<α>
    (ma: &α mut i32, mb: &α mut i32)
     -> &α mut i32 {
  if *ma >= *mb { ma } else { mb }
}

fn test(mut a: i32, mut b: i32) {
  *take_max(&mut a, &mut b) += 7;
  assert!((a - b).abs() >= 7);
}
```

Example of RustHorn's Translation

Rust 

ML 

```
fn take_max<α>
    (ma: &α mut i32, mb: &α mut i32)
     -> &α mut i32 {
  if *ma >= *mb { ma } else { mb }
}

fn test(mut a: i32, mut b: i32) {
  *take_max(&mut a, &mut b) += 7;
  assert!((a - b).abs() >= 7);
}
```

```
let take_max (a, a') (b, b') =
  if a >= b then
      (assume(b' = b); (a, a'))
  else (assume(a' = a); (b, b'))

let test a b =
  let a' = rand() in let b' = rand() in
  let (r, r') =
    take_max (a, a') (b, b') in
  assume(r' = r + 7);
  assert(abs (a' - b') >= 7);
```

RustHorn's Idea in Diverse Contexts

RustHorn's Idea in Diverse Contexts

- ✦ **RustHorn: Fully automated Rust verifier**
  - ▸ **Find invariants** with CHC solvers [Bjørner+ '15]

RustHorn's Idea in Diverse Contexts

- **RustHorn: Fully automated Rust verifier**
  - **Find invariants** with CHC solvers [Bjørner+ '15]

- **Creusot: Automated Rust verifier** [Denis+ '22]

RustHorn's Idea in Diverse Contexts

- **RustHorn: Fully automated Rust verifier**
  - **Find invariants** with CHC solvers [Bjørner+ '15]

- **Creusot: Automated Rust verifier** [Denis+ '22]

- **RusSOL: Rust program synthesizer** [Fiala+ '23]

RustHorn's Idea in Diverse Contexts

- **RustHorn: Fully automated Rust verifier**
  - **Find invariants** with CHC solvers [Bjørner+ '15]

- **Creusot: Automated Rust verifier** [Denis+ '22]

- **RusSOL: Rust program synthesizer** [Fiala+ '23]
- **Thrust: Rust verifier with refinement types** [Ogawa+ '25]

RustHorn's Idea in Diverse Contexts

- **RustHorn: Fully automated Rust verifier**
  - **Find invariants** with CHC solvers [Bjørner+ '15]

- **Creusot: Automated Rust verifier** [Denis+ '22]

- **RusSOL: Rust program synthesizer** [Fiala+ '23]
- **Thrust: Rust verifier with refinement types** [Ogawa+ '25]
- **Verus: New automated Rust verifier** [Lattuada+ '23/'24]
  - Initiated at **Microsoft Research**, highly practical

I'm Happy

Google Scholar SIGN IN

Yusuke Matsushita

FOLLOW

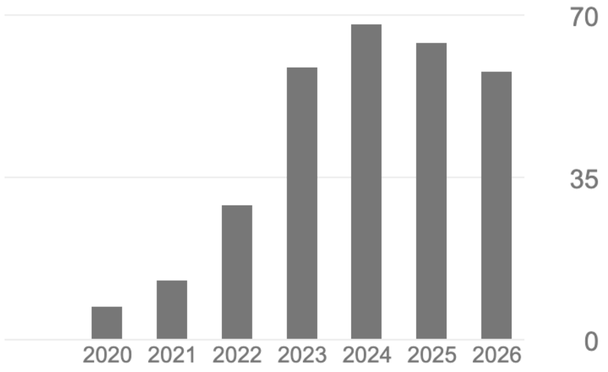
Kyoto University
Verified email at fos.kuis.kyoto-u.ac.jp - Homepage
Computer Science Programming Languages Machine Learning

GET MY OWN PROFILE

TITLE	CITED BY	YEAR
RustHorn: CHC-based Verification for Rust Programs Y Matsushita, T Tsukada, N Kobayashi ACM Transactions on Programming Languages and Systems (TOPLAS) 43 (4), 1-54	108	2021
RustHornBelt: A Semantic Foundation for Functional Verification of Rust Programs with Unsafe Code Y Matsushita, X Denis, JH Jourdan, D Dreyer Proceedings of the 43rd ACM SIGPLAN Conference on Programming Language …	94	2022
RustHorn: CHC-Based Verification for Rust Programs Y Matsushita, T Tsukada, N Kobayashi European Symposium on Programming (ESOP), 484-514	65	2020
Nola: Later-Free Ghost State for Verifying Termination in Iris Y Matsushita, T Tsukada Proceedings of the ACM on Programming Languages 9 (PLDI)	7	2025

Cited by

	All	Since 2021
Citations	298	291
h-index	5	5
i10-index	3	3



Public access VIEW ALL

0 articles 6 articles

Why Software Science & Engineering?

Why Software Science & Engineering?

- **AIs are drastically changing software development**
  - Humans write less code, more high-level instructions

Why Software Science & Engineering?

- **AIs are drastically changing software development**
  - Humans write less code, more high-level instructions
- **Writing code is easy; Achieving high quality is hard**
  - Systematic management of the software quality is crucial

Why Software Science & Engineering?

- **AIs are drastically changing software development**
  - Humans write less code, more high-level instructions
- **Writing code is easy; Achieving high quality is hard**
  - Systematic management of the software quality is crucial
- **Formal methods can really help**
  - Very strong safeguards, robust to human/AI errors
  - Writing proofs is becoming easy thanks to AIs + advances in SwS/E

Why Science?

Why Science?

- **Humans' intellectual curiosity is valuable**
  - We should not give up thinking

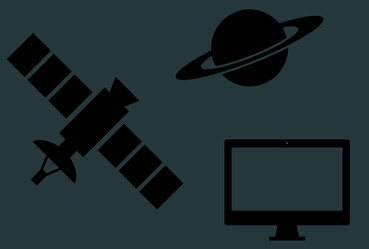
Why Science?

- **Humans' intellectual curiosity is valuable**
  - We should not give up thinking
- **Keep distance from capitalism & money games**
  - It can be hard to stay sane amid a rapid flow

Why Science?

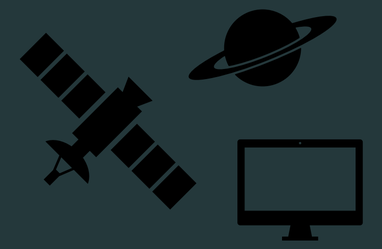
- **Humans' intellectual curiosity is valuable**
  - We should not give up thinking
- **Keep distance from capitalism & money games**
  - It can be hard to stay sane amid a rapid flow
- **Engage in intellectual exploration rooted in ancient times**





Thank you!

Best of luck for your future



ありがとうございました

皆さんの未来に幸あれ