UCL COMPUTER SCIENCE

UCL

The Inaugural Lecture of Alexandra Silva

Tuesday 18th December 2018

UCL ENGINEERING
Change the world

CLAM: Coalgebraic Learning for Automated Modelling

Alexandra Silva

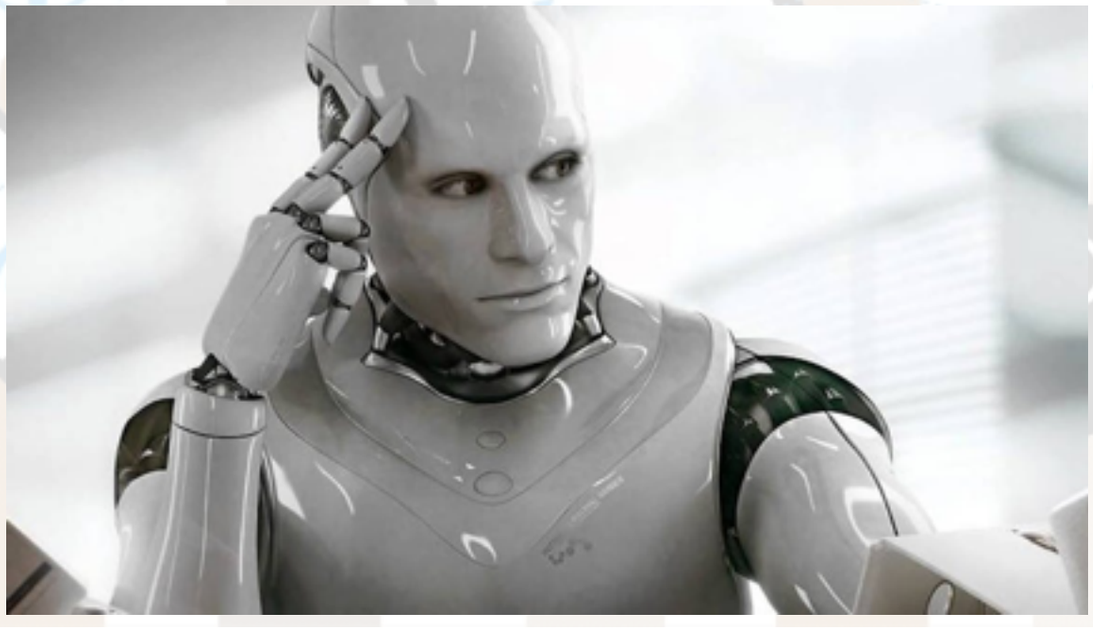
UCL ENGINEERING
Change the world

UCL

Digital world

Source images: Tom Buehler/MIT CSAIL; https://www.techspot.com/;https://smallbiztrends.com

Digital world



Source images: Tom Buehler/MIT CSAIL; https://www.techspot.com/;https://smallbiztrends.com

Digital world

Trust?

Source images: Tom Buehler/MIT CSAIL; https://www.techspot.com/;https://smallbiztrends.com

Digital world

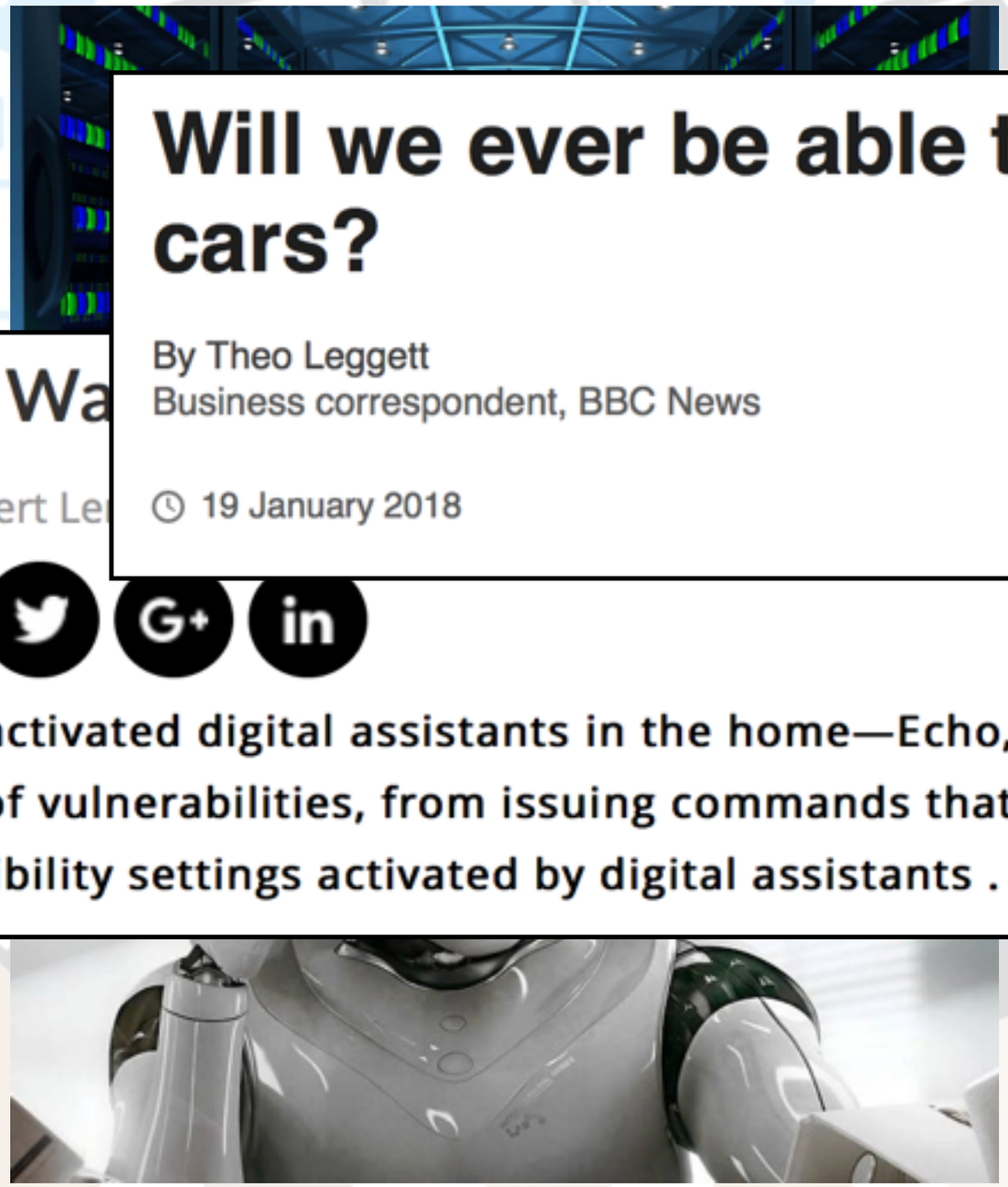
Five Ways Digital Assistants Pose Security Threats in Home, Office

By: Robert Lemos | July 02, 2018

Voice-activated digital assistants in the home—Echo, Cortana, Alexa and Siri—open up a host of new types of vulnerabilities, from issuing commands that aren't audible to humans to exploiting the accessibility settings activated by digital assistants .

Source images: Tom Buehler/MIT CSAIL; https://www.techspot.com/;https://smallbiztrends.com

Digital world

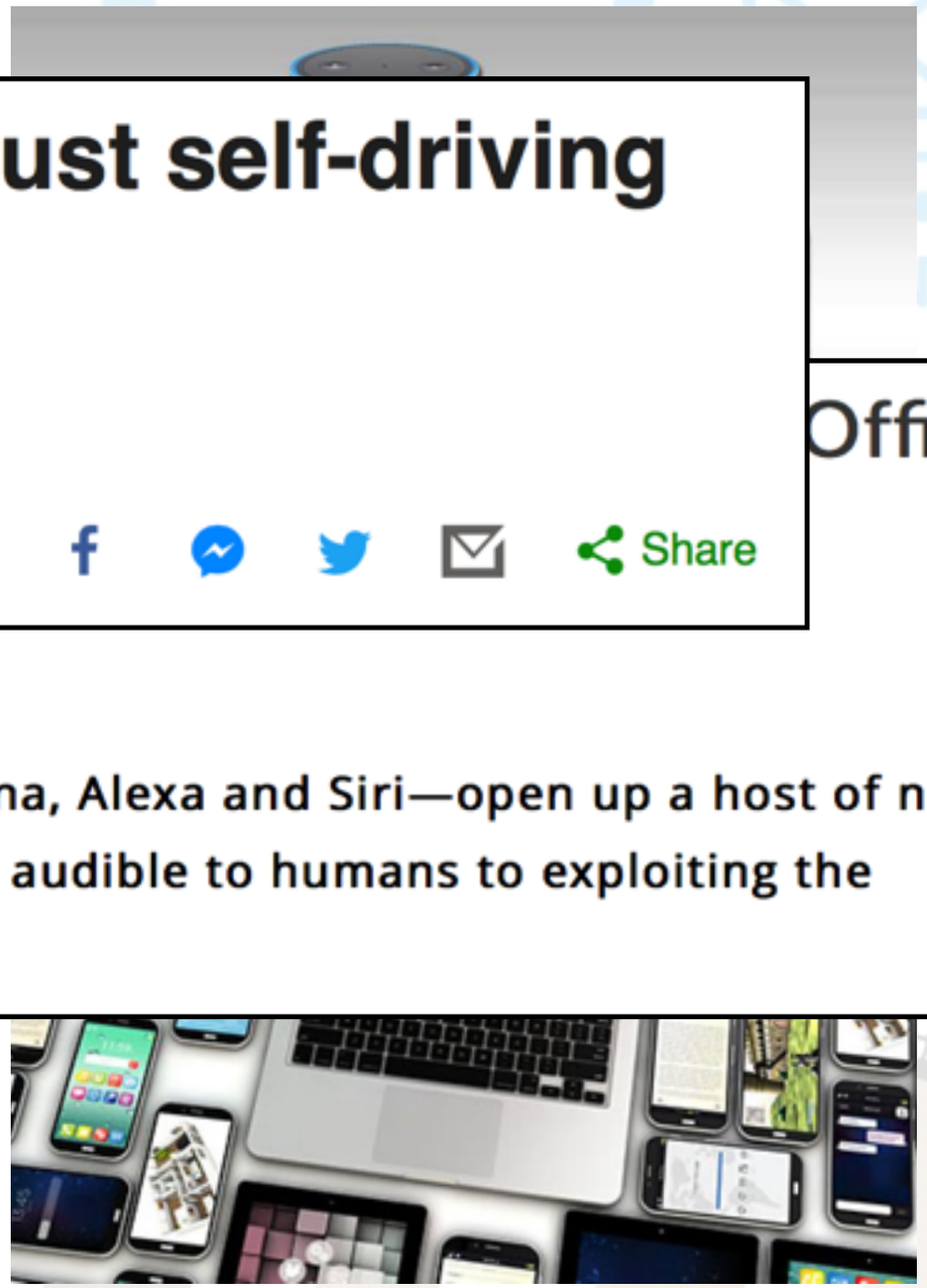


Will we ever be able to trust self-driving cars?

By Theo Leggett
Business correspondent, BBC News

19 January 2018

Share



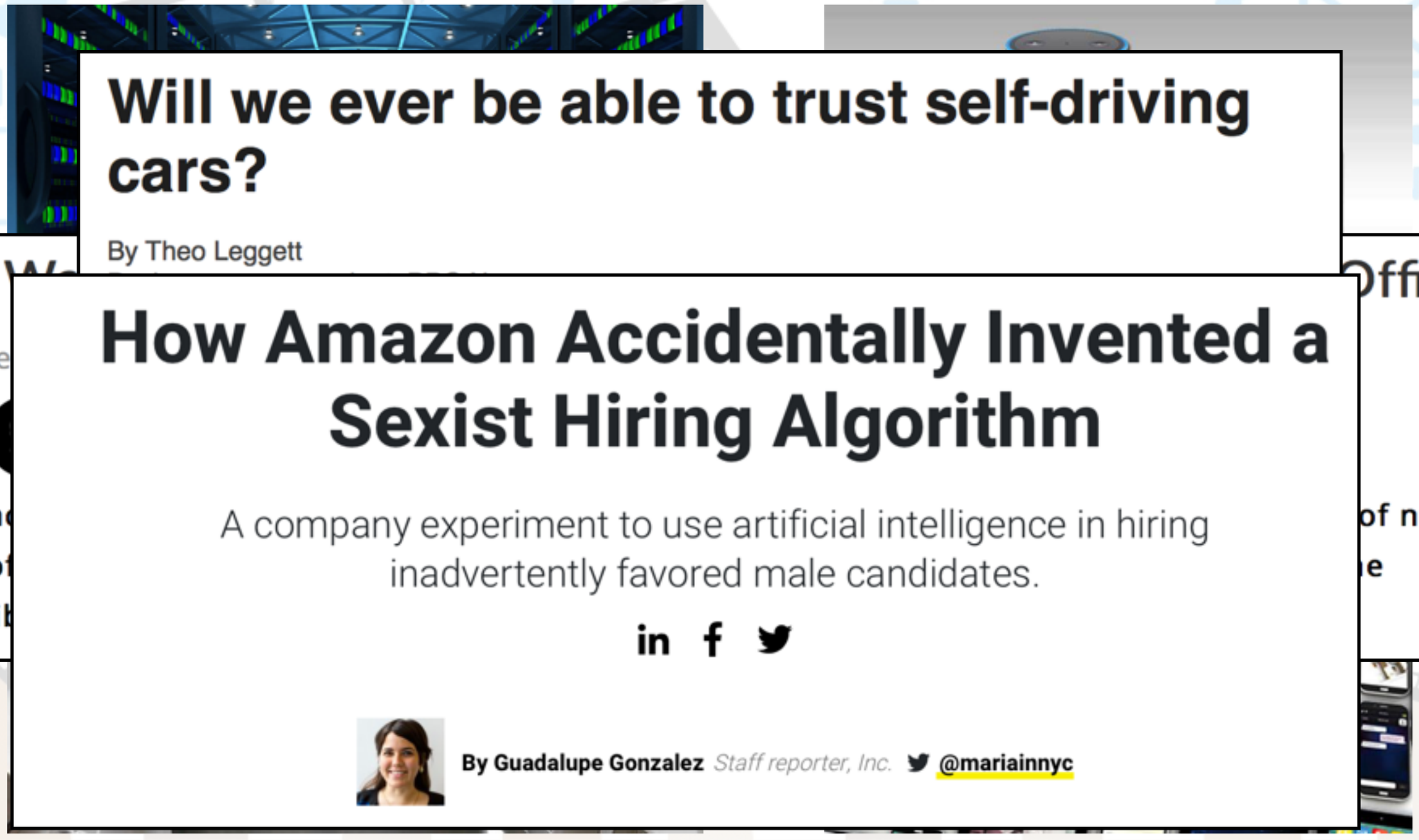
Five Wa… Office

By: Robert Le…

Voice-activated digital assistants in the home—Echo, Cortana, Alexa and Siri—open up a host of new types of vulnerabilities, from issuing commands that aren't audible to humans to exploiting the accessibility settings activated by digital assistants .

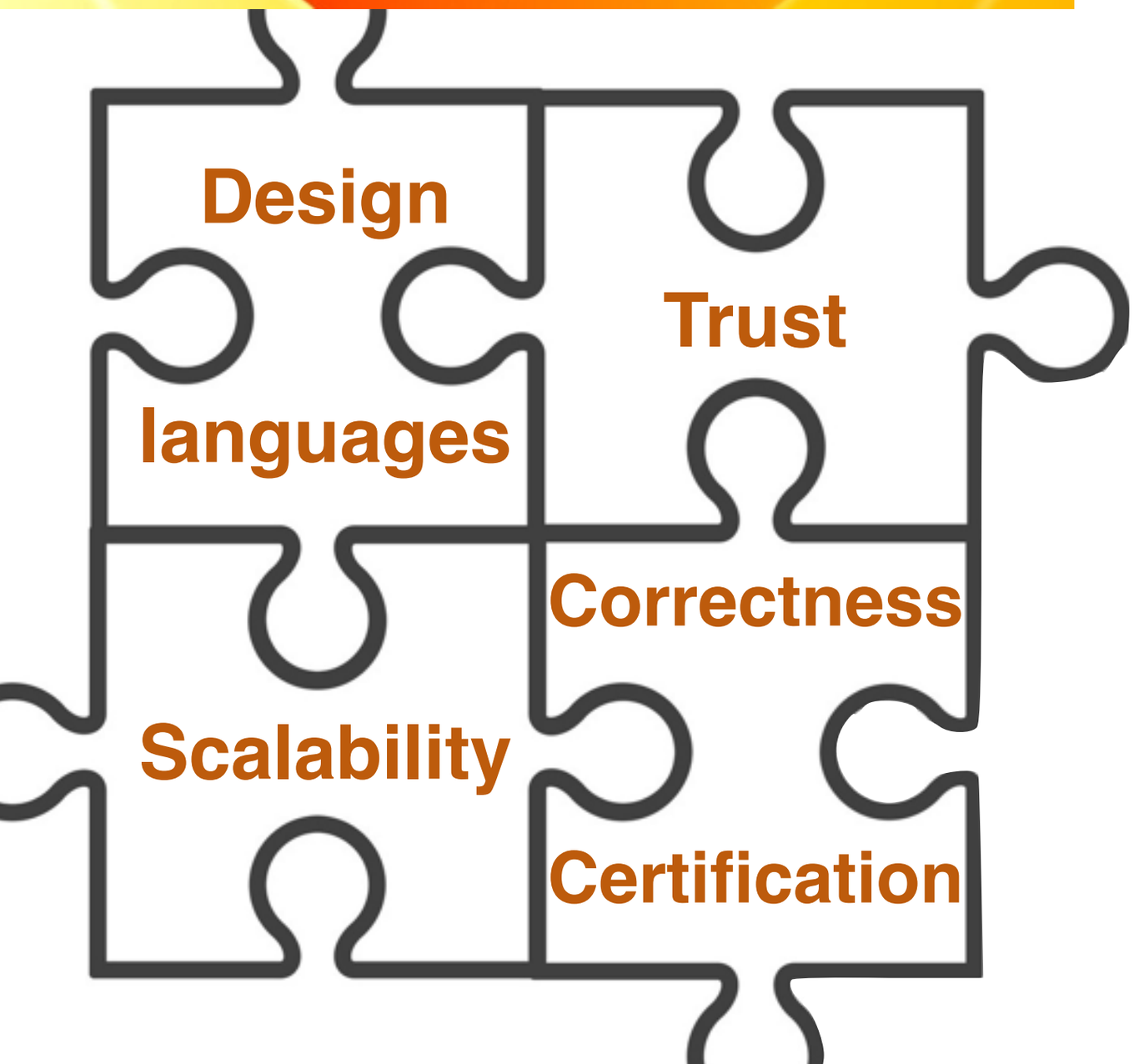
Source images: Tom Buehler/MIT CSAIL; https://www.techspot.com/;https://smallbiztrends.com

Digital world



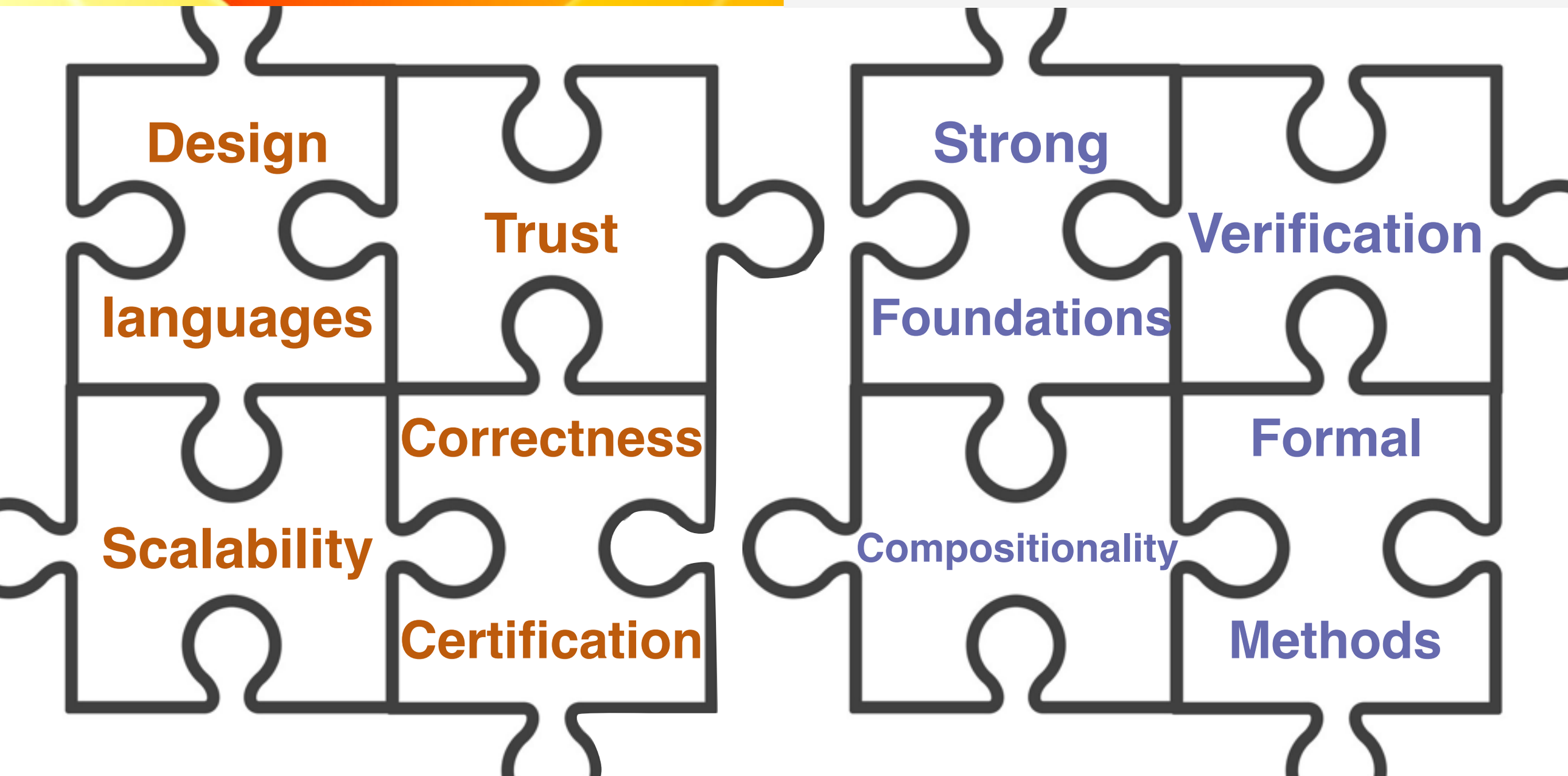
Source images: Tom Buehler/MIT CSAIL; https://www.techspot.com/;https://smallbiztrends.com

THE BIG QUESTIONS



THE BIG QUESTIONS

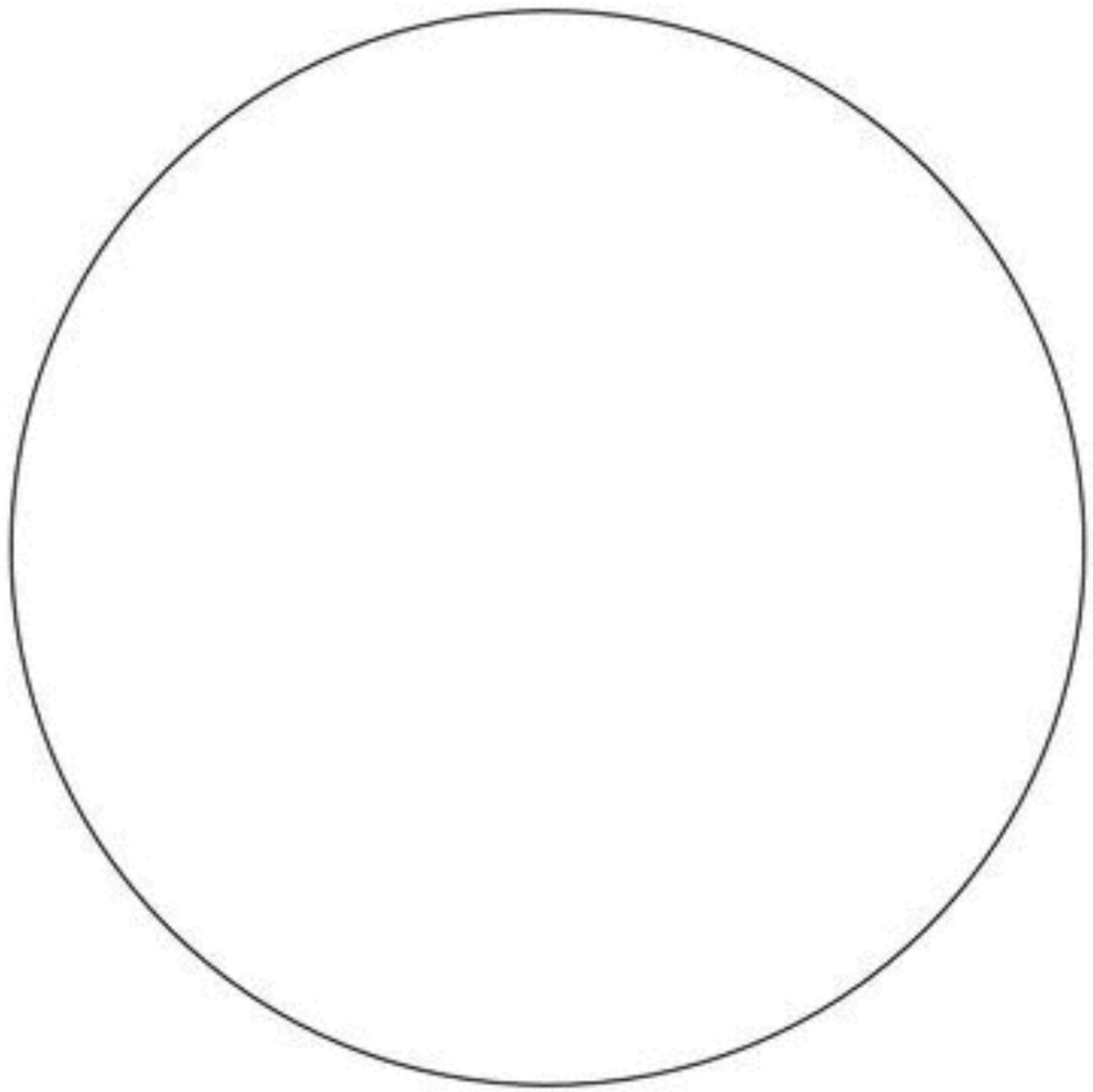
BRIEF ANSWERS TO THE BIG QUESTIONS



My research world

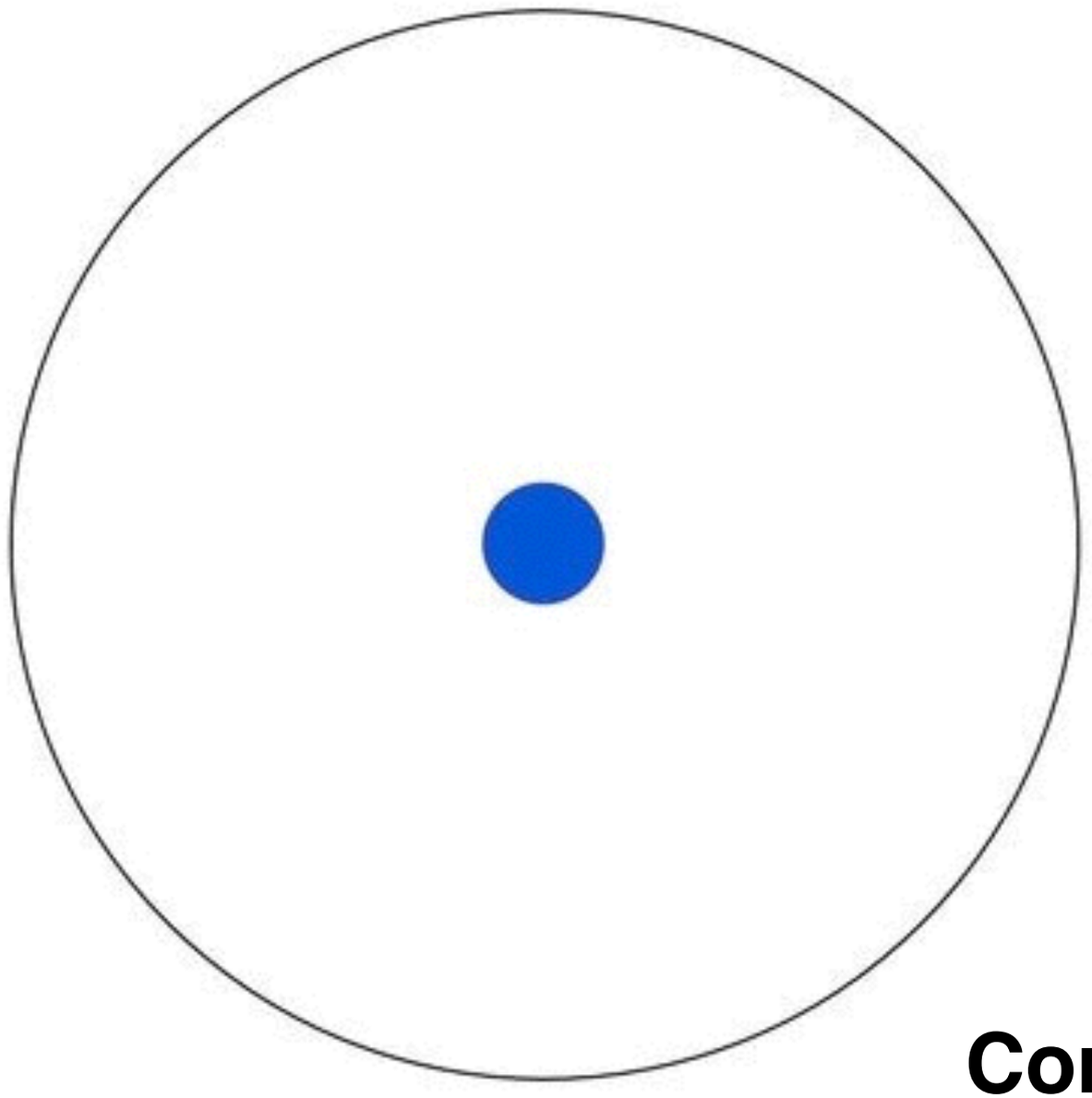
Images: http://gizmodo.com/5613794/what-is-exactly-a-doctorate

My research world



Images: http://gizmodo.com/5613794/what-is-exactly-a-doctorate

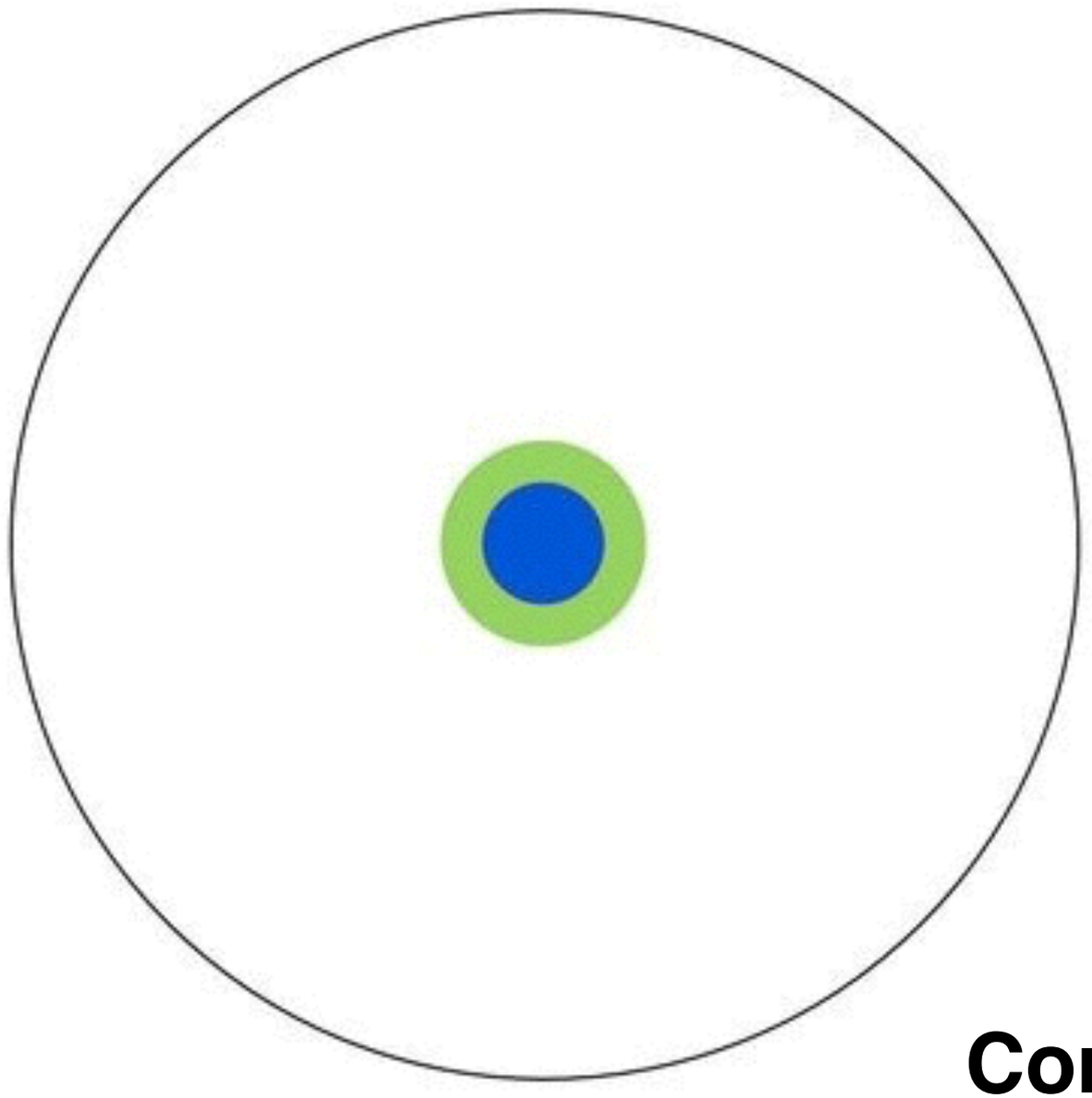
My research world



Computer Science

Images: http://gizmodo.com/5613794/what-is-exactly-a-doctorate

My research world

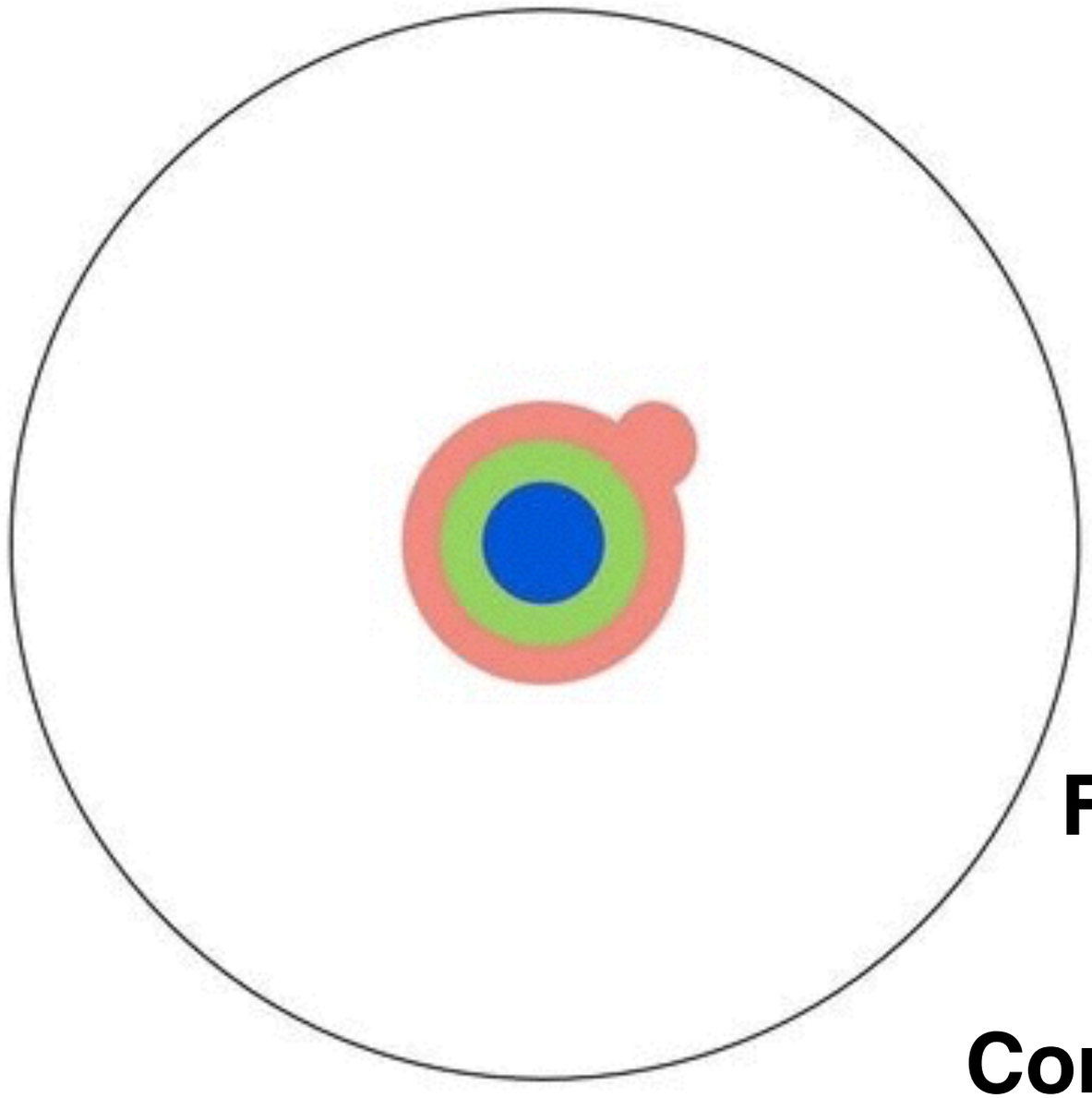


Verification

Computer Science

Images: http://gizmodo.com/5613794/what-is-exactly-a-doctorate

My research world



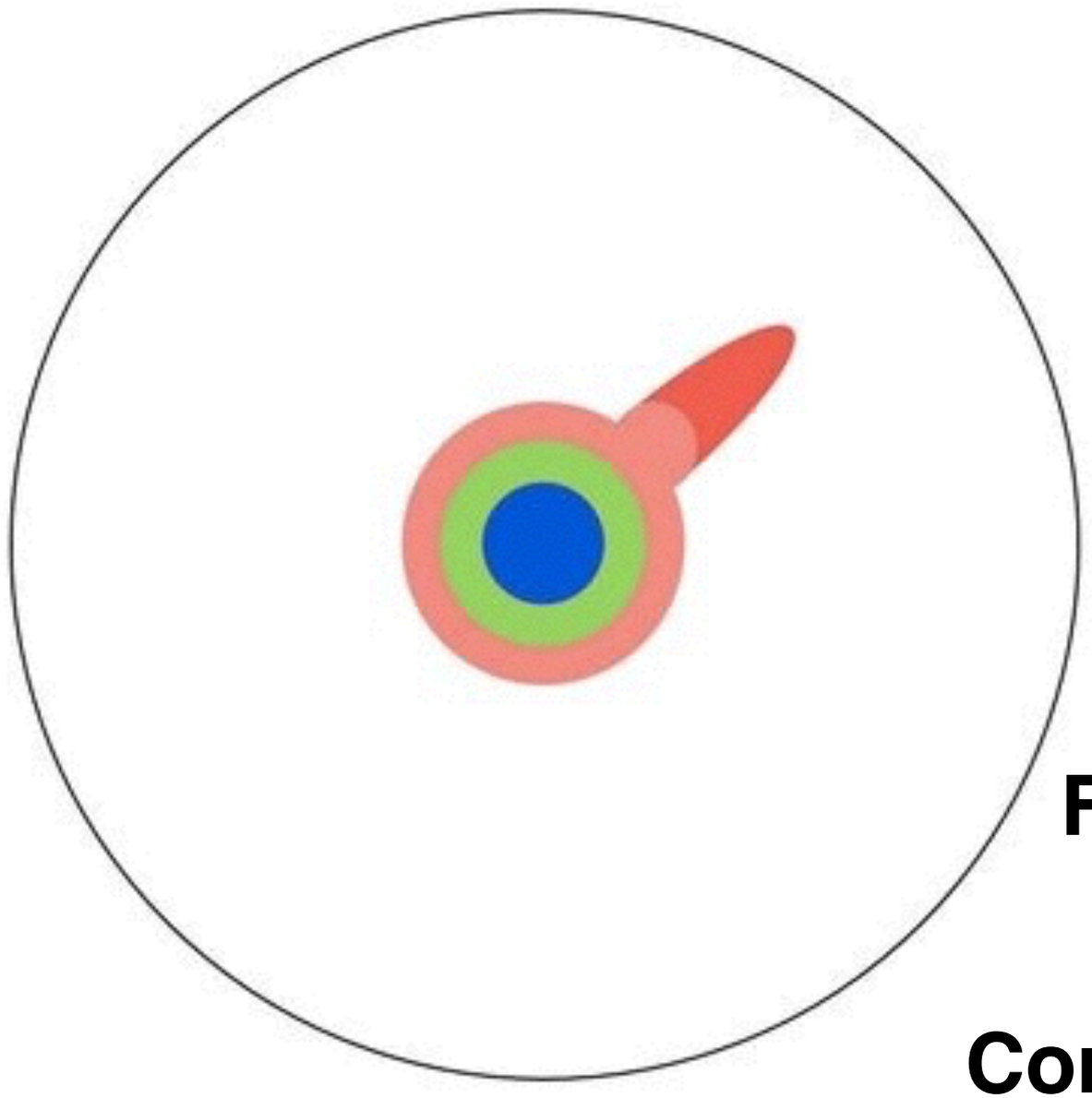
Formal methods

Verification

Computer Science

Images: http://gizmodo.com/5613794/what-is-exactly-a-doctorate

My research world



PL semantics

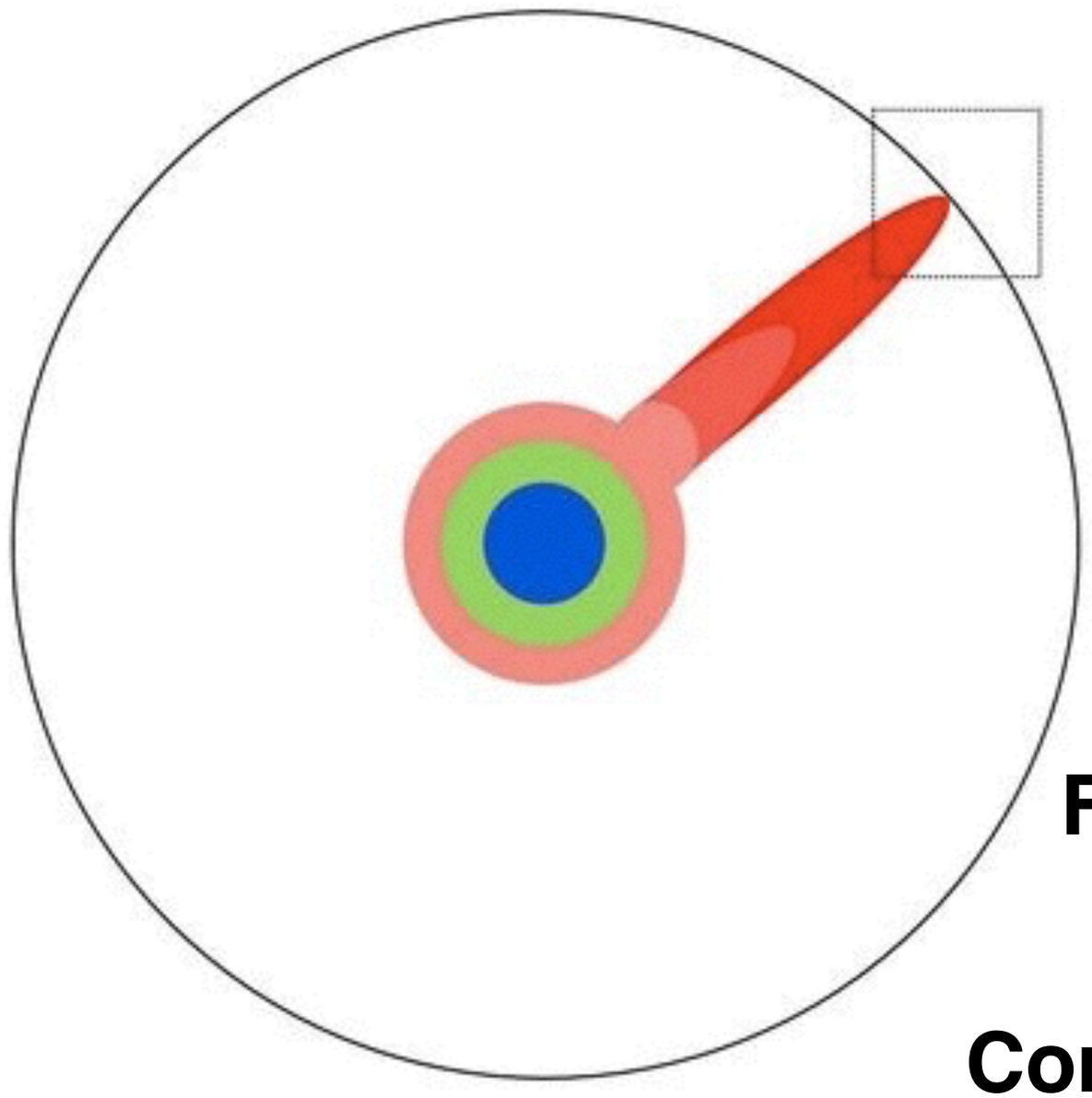
Formal methods

Verification

Computer Science

Images: http://gizmodo.com/5613794/what-is-exactly-a-doctorate

My research world



(Co)algebra

PL semantics

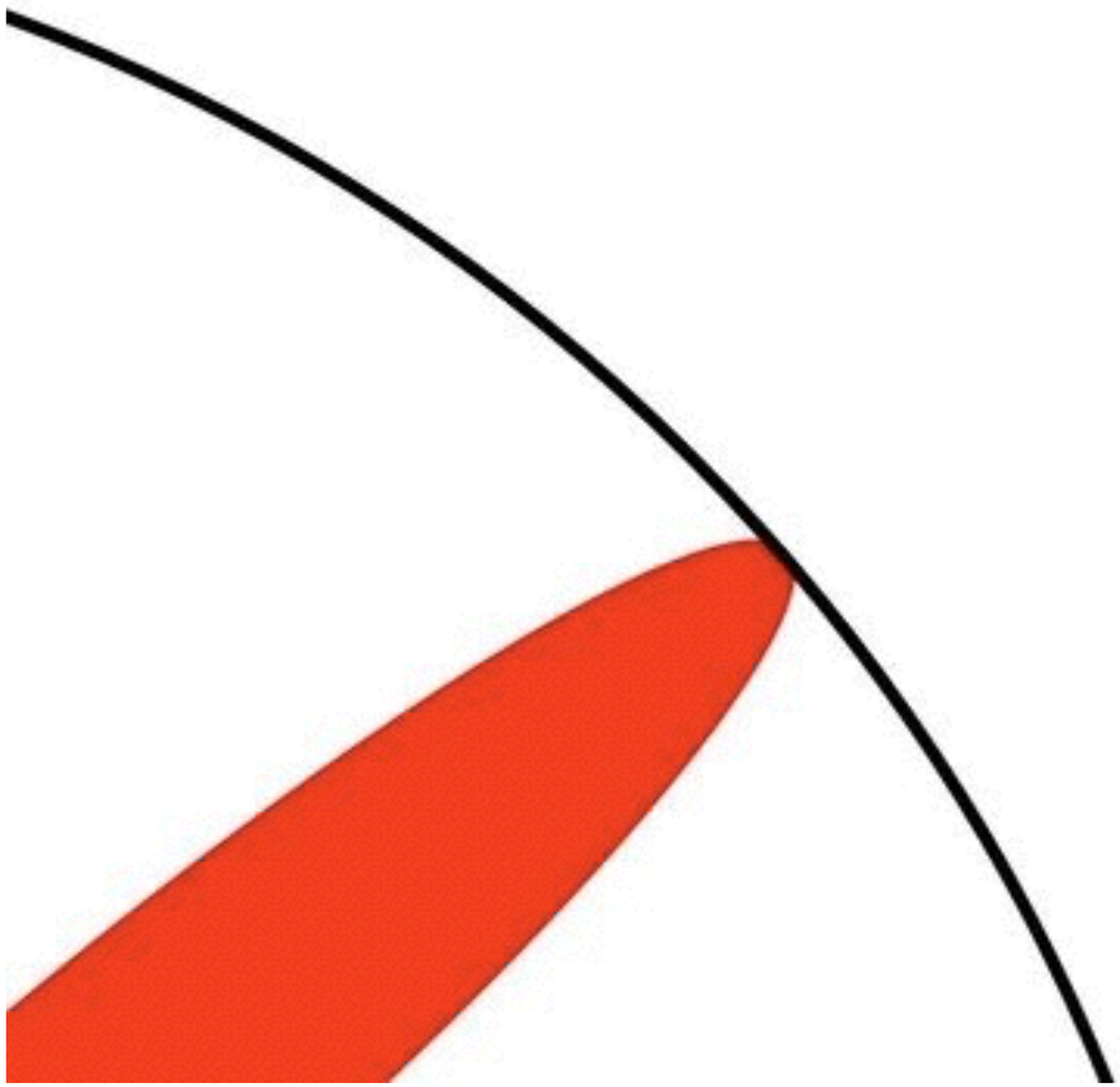
Formal methods

Verification

Computer Science

Images: http://gizmodo.com/5613794/what-is-exactly-a-doctorate

My research world



(Co)algebra

PL semantics

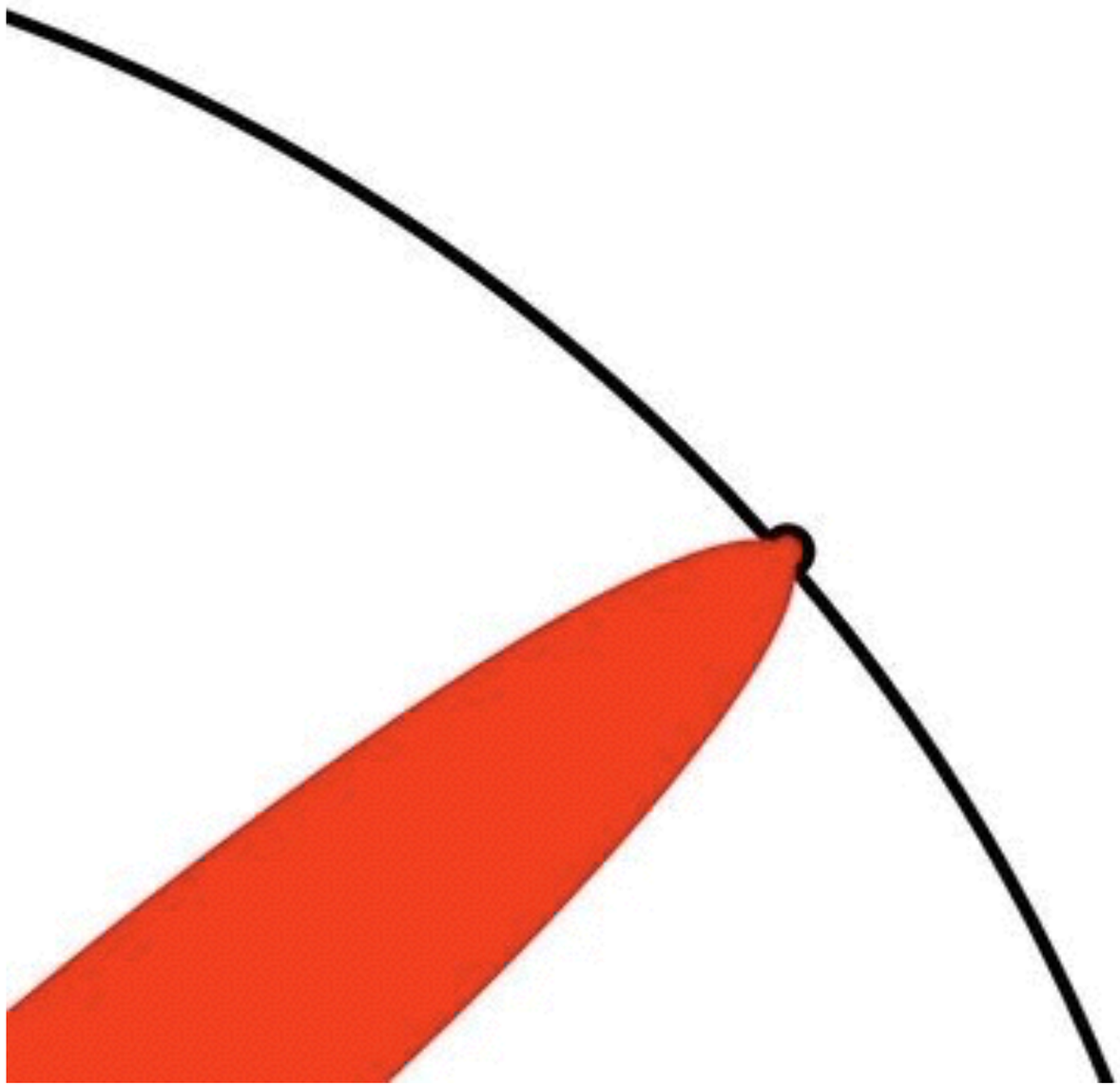
Formal methods

Verification

Computer Science

Images: http://gizmodo.com/5613794/what-is-exactly-a-doctorate

My research world



(Co)algebra

PL semantics

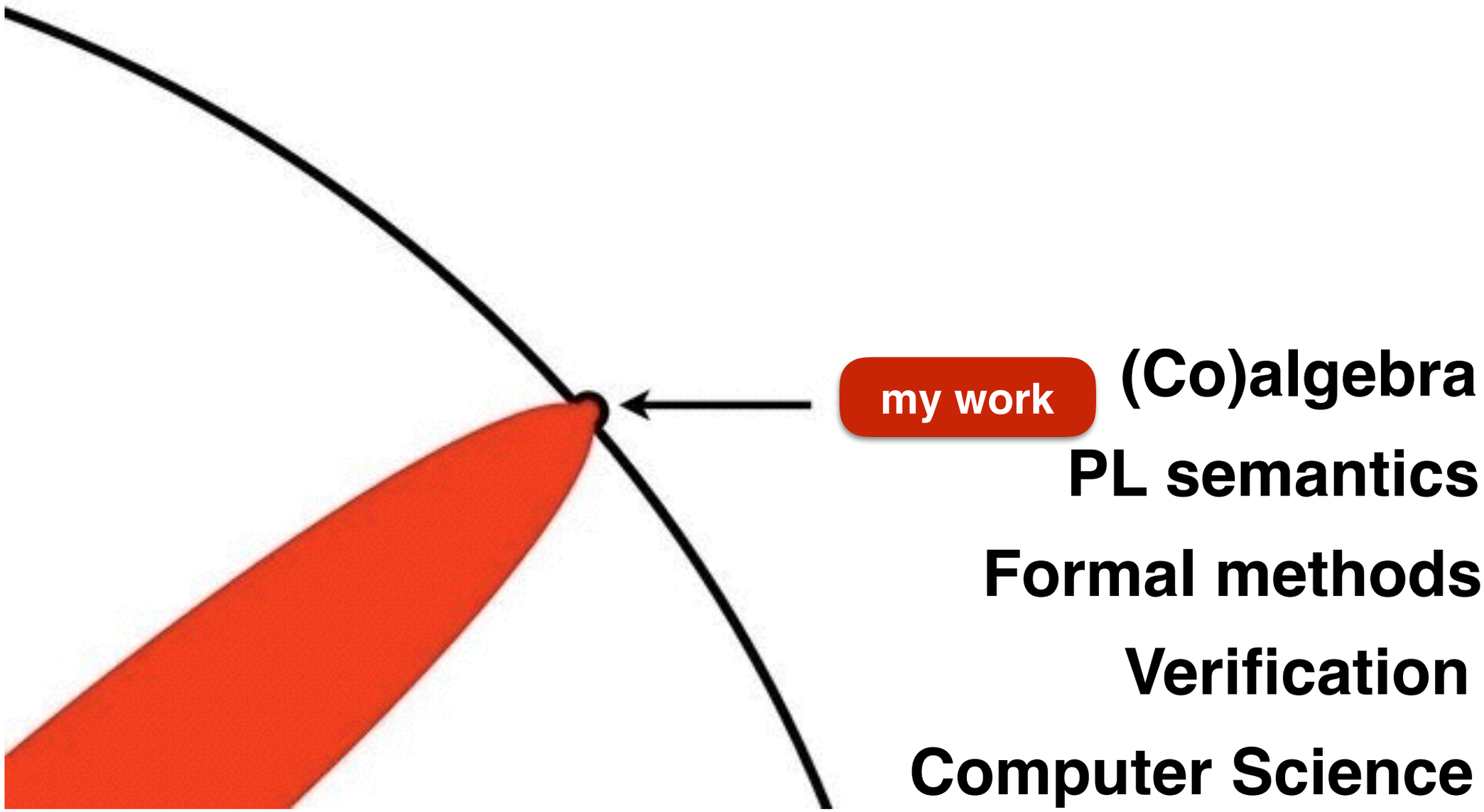
Formal methods

Verification

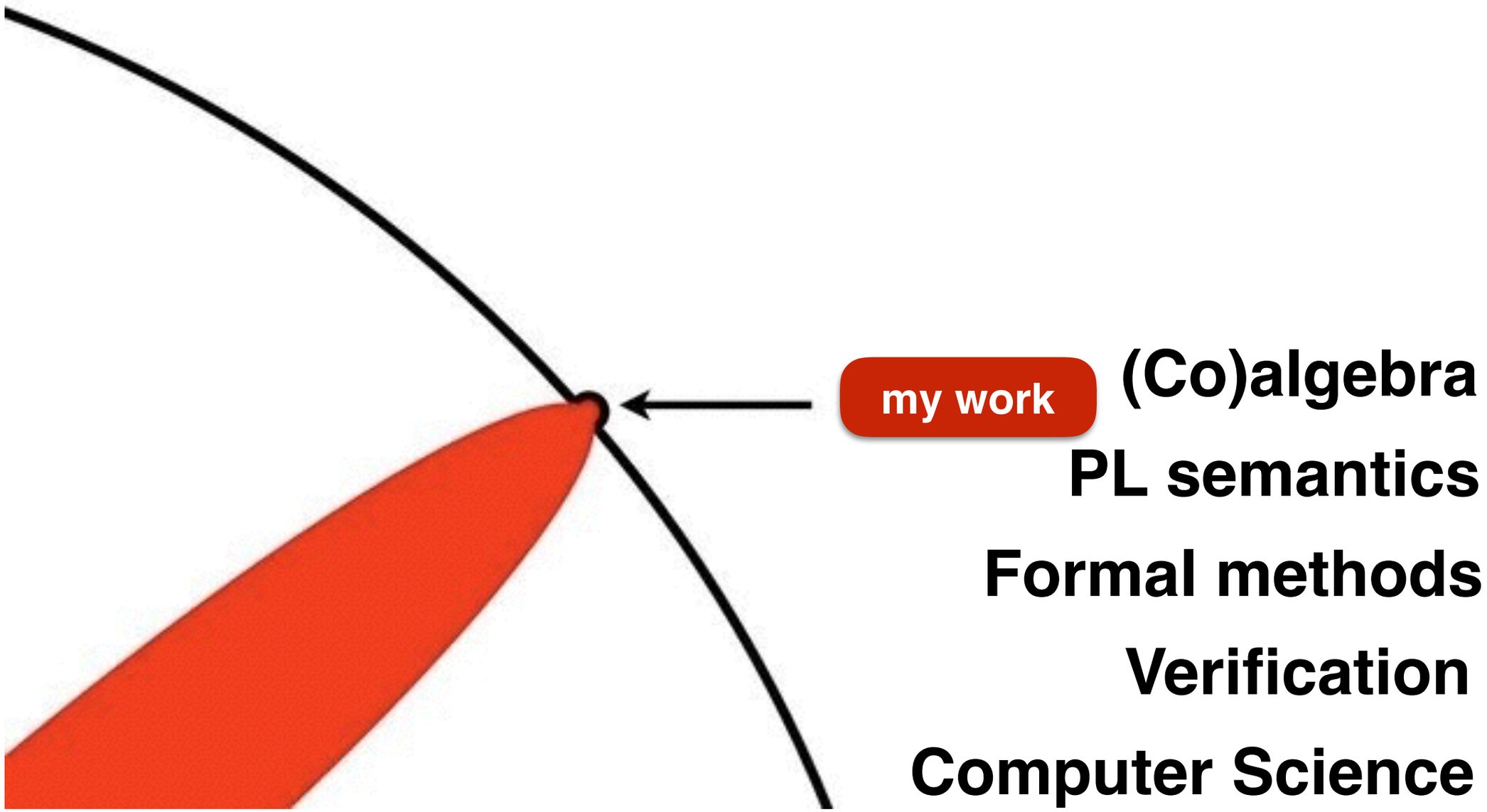
Computer Science

Images: http://gizmodo.com/5613794/what-is-exactly-a-doctorate

My research world

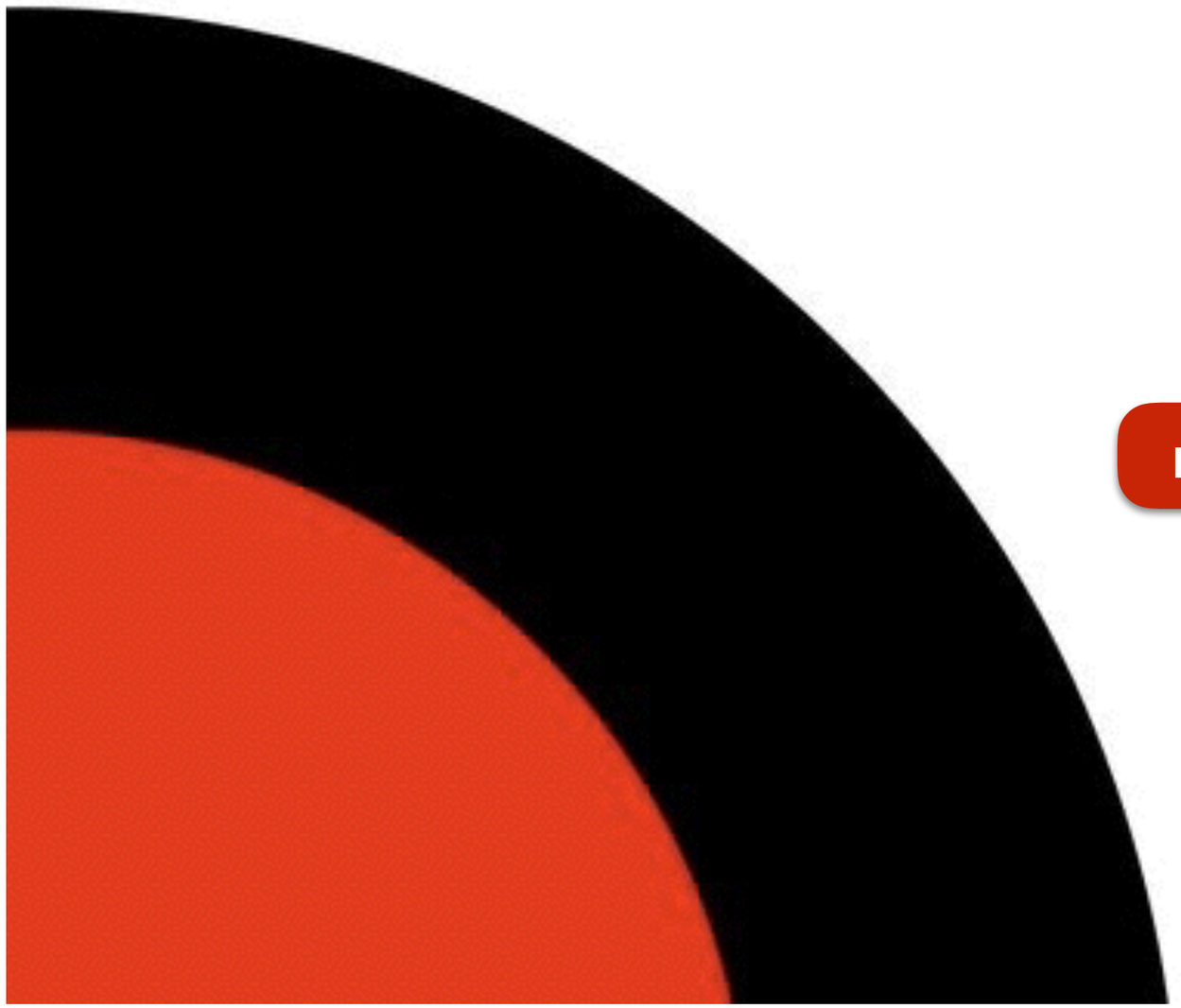


My research world



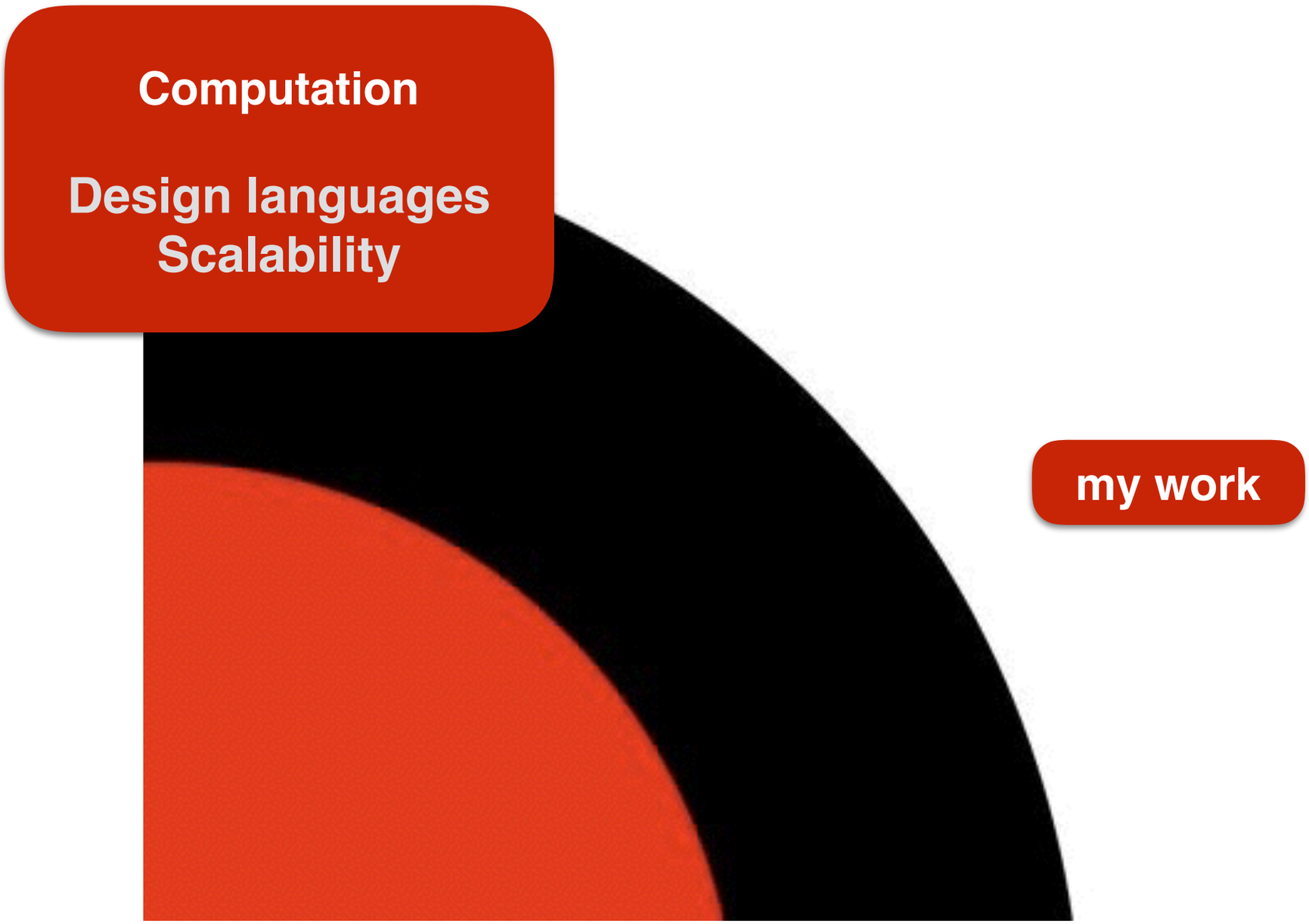
Professor of Algebra, Semantics, and Computation

My research world



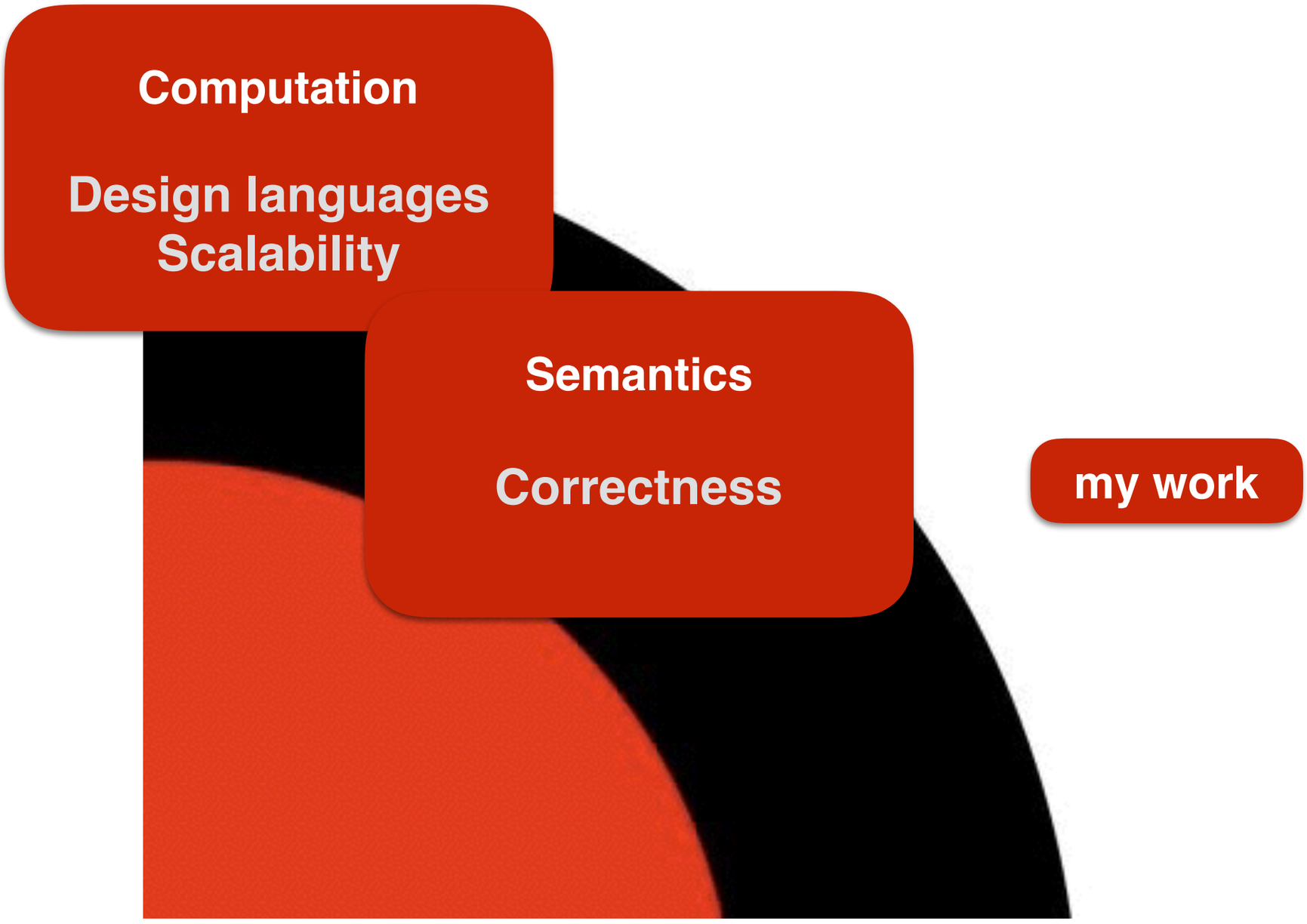
Professor of Algebra, Semantics, and Computation

My research world



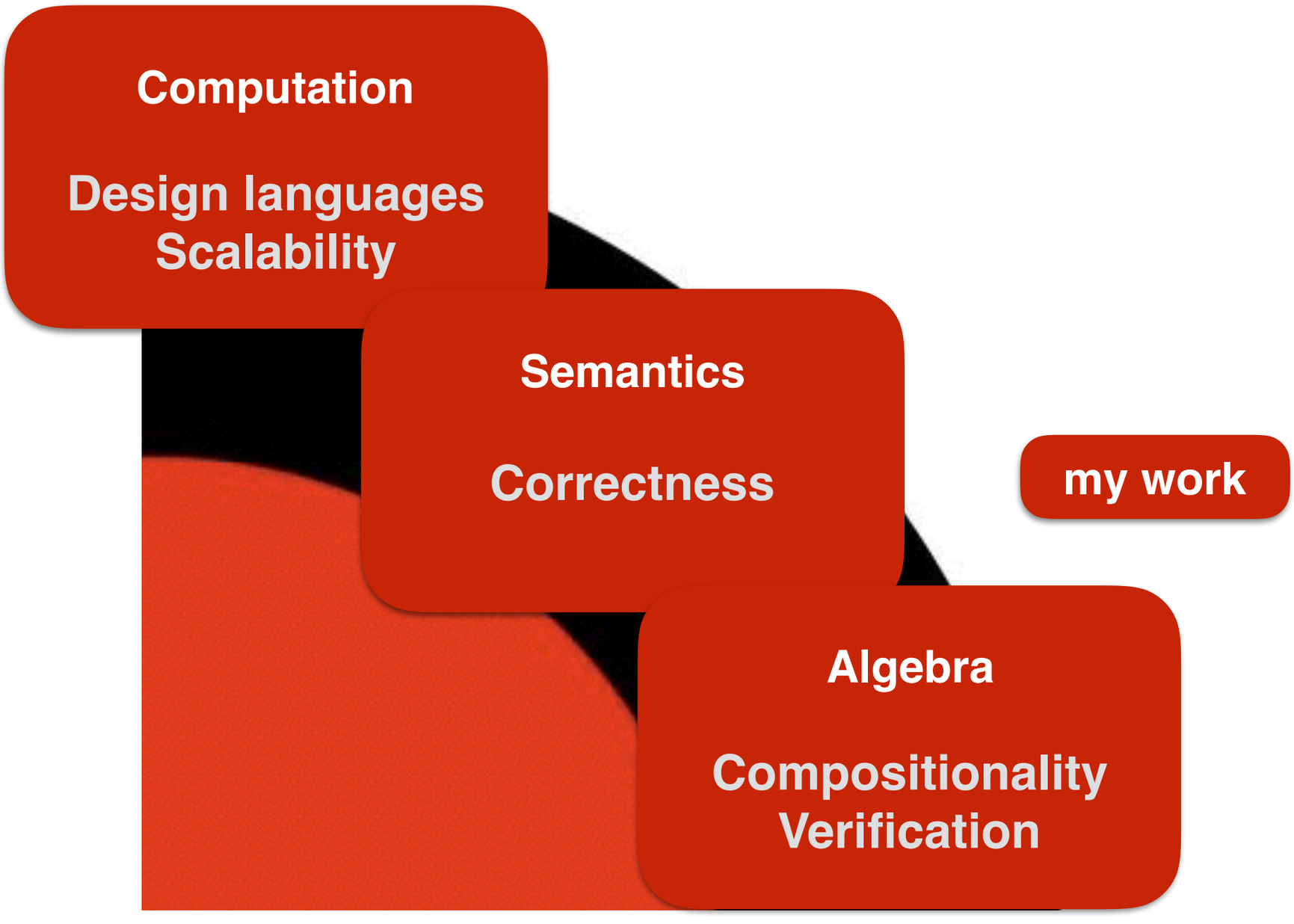
Professor of Algebra, Semantics, and Computation

My research world



Professor of Algebra, Semantics, and Computation

My research world

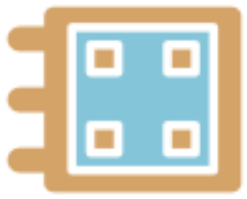


Professor of Algebra, Semantics, and Computation

Programmability and Performance

Computers	Graphics	Machine Learning	Networks
C, Java, Python	Open CL	TensorFlow	P4
Compiler	Compiler	Compiler	Compiler
CPU	GPU	TPU	Tofino

Source: https://www.barefootnetworks.com/technology/

Computers	Graphics	Machine Learning	Networks
C, Java, Python	Open CL	TensorFlow	P4
Compiler	Compiler	Compiler	Compiler
			
CPU	GPU	TPU	Tofino

Source: https://www.barefootnetworks.com/technology/

Computers	Graphics	Machine Learning	Networks
C, Java, Python	Open CL	TensorFlow	P4
Compiler	Compiler	Compiler	Compiler
CPU	GPU	TPU	Tofino

Where can things go wrong?

Source: https://www.barefootnetworks.com/technology/

Computers | Graphics | Machine Learning | Networks

C, Java, Python | Open CL | TensorFlow | P4

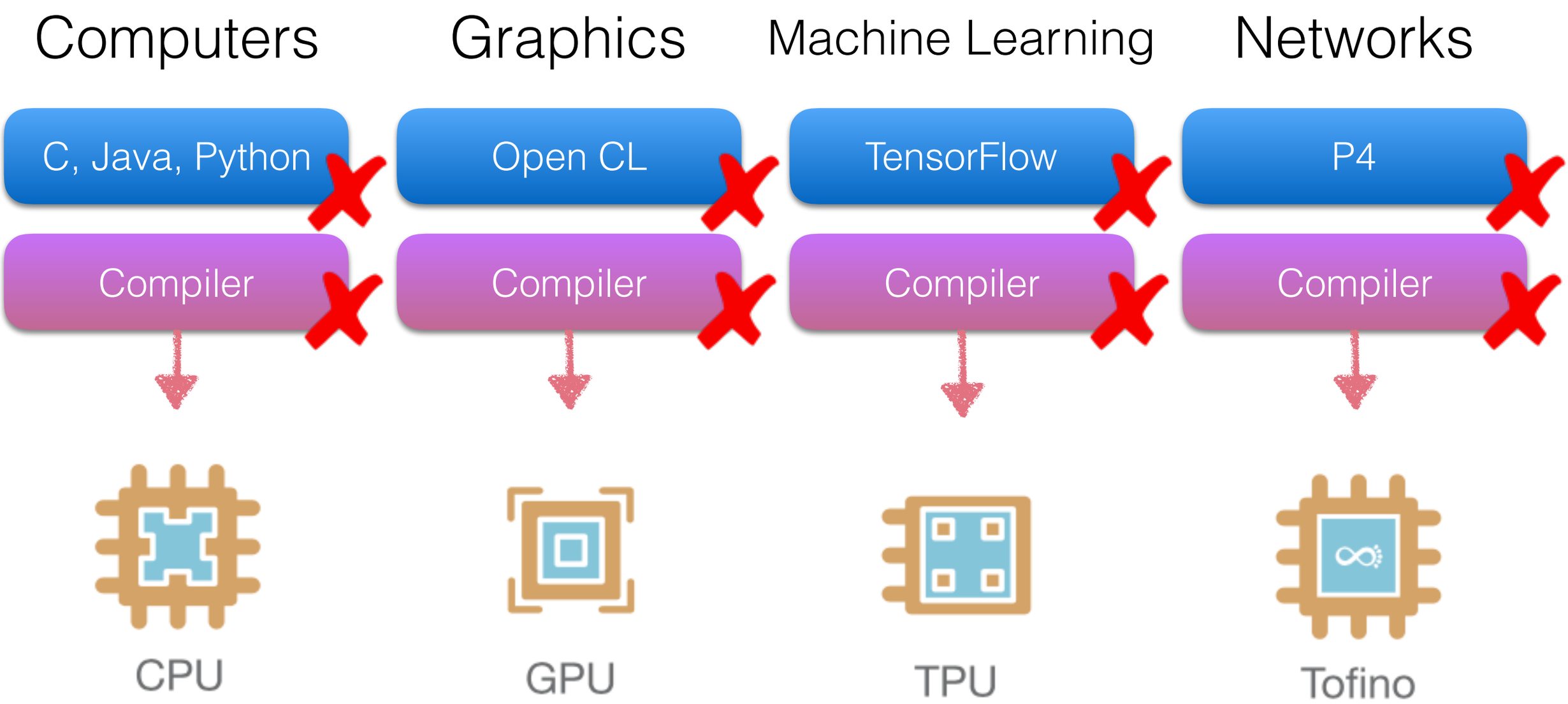
Compiler | Compiler | Compiler | Compiler

CPU | GPU | TPU | Tofino

Where can things go wrong?

Language semantics

Source: https://www.barefootnetworks.com/technology/



Where can things go wrong?

Language semantics

Compiler translation

Source: https://www.barefootnetworks.com/technology/

Computers	Graphics	Machine Learning	Networks
C, Java, Python	Open CL	TensorFlow	P4
Compiler	Compiler	Compiler	Compiler
CPU	GPU	TPU	Tofino

Where can things go wrong?

- Language semantics
- Compiler translation
- Hardware

Source: https://www.barefootnetworks.com/technology/

Computers | Graphics | Machine Learning | Networks

C, Java, Python | Open CL | TensorFlow | P4

Compiler | Compiler | Compiler | Compiler

CPU | GPU | TPU | Tofino

Can Formal Methods help?

Precise semantics | **Certified compiler** | **Hardware testing**

Source: https://www.barefootnetworks.com/technology/

Computers | Graphics | Machine Learning | Networks

C, Java, Python | Open CL | TensorFlow | P4

Compiler | Compiler | Compiler | Compiler

CPU | GPU | TPU | Tofino

Can Formal Methods help?

Expensive

Precise semantics

Certified compiler

Hardware testing

Source: https://www.barefootnetworks.com/technology/

Computers | Graphics | Machine Learning | Networks

C, Java, Python | Open CL | TensorFlow | P4

Compiler | Compiler | Compiler | Compiler

CPU | GPU | TPU | Tofino

Can we do better?

Precise semantics

Certified compiler

Hardware testing

Expensive

Source: https://www.barefootnetworks.com/technology/

Computers | Graphics | Machine Learning | Networks

C, Java, Python | Open CL | TensorFlow | P4

Compiler | Compiler | Compiler | Compiler

CPU | GPU | TPU | Tofino

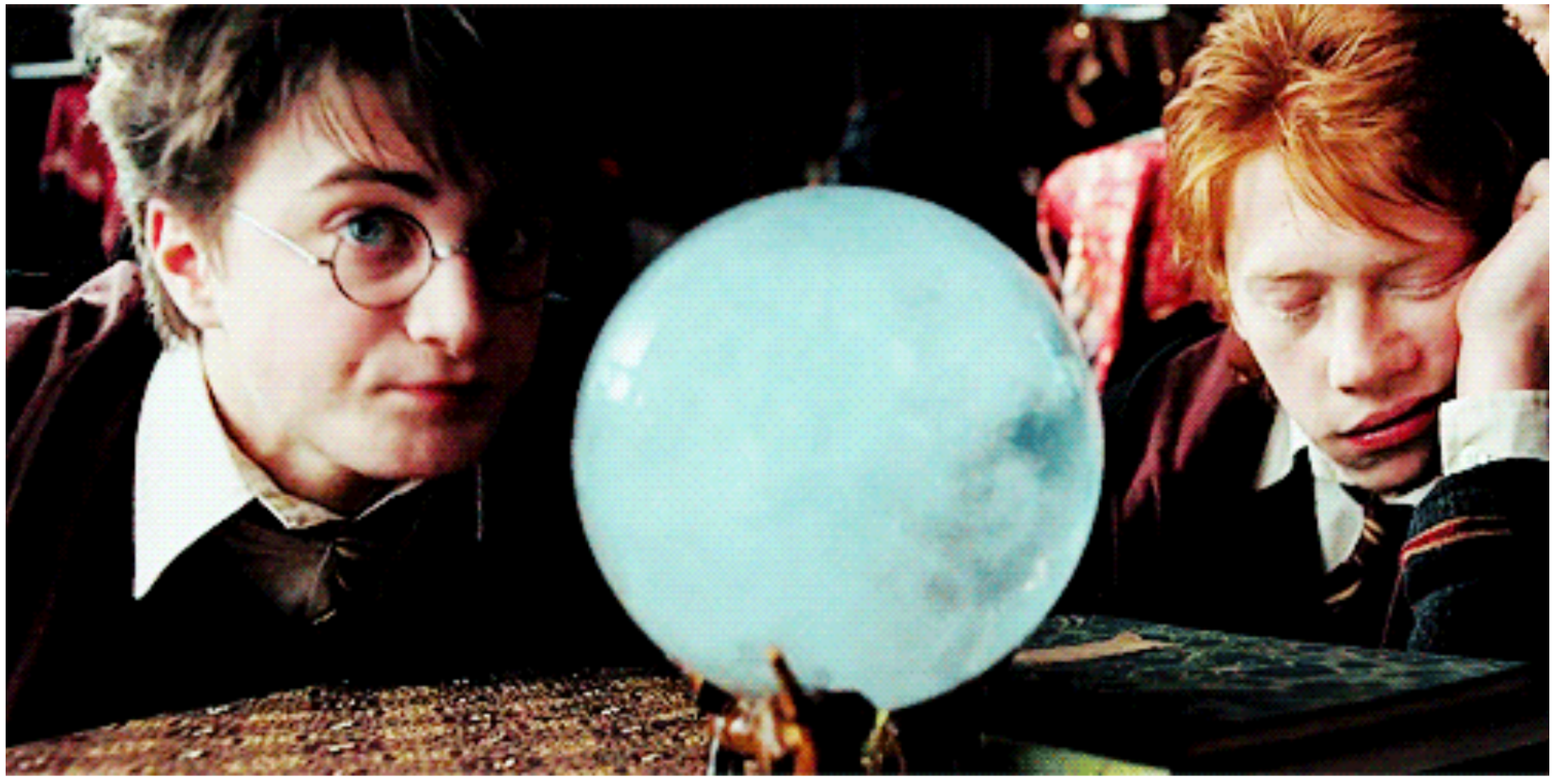
Can we do better?

Precise semantics

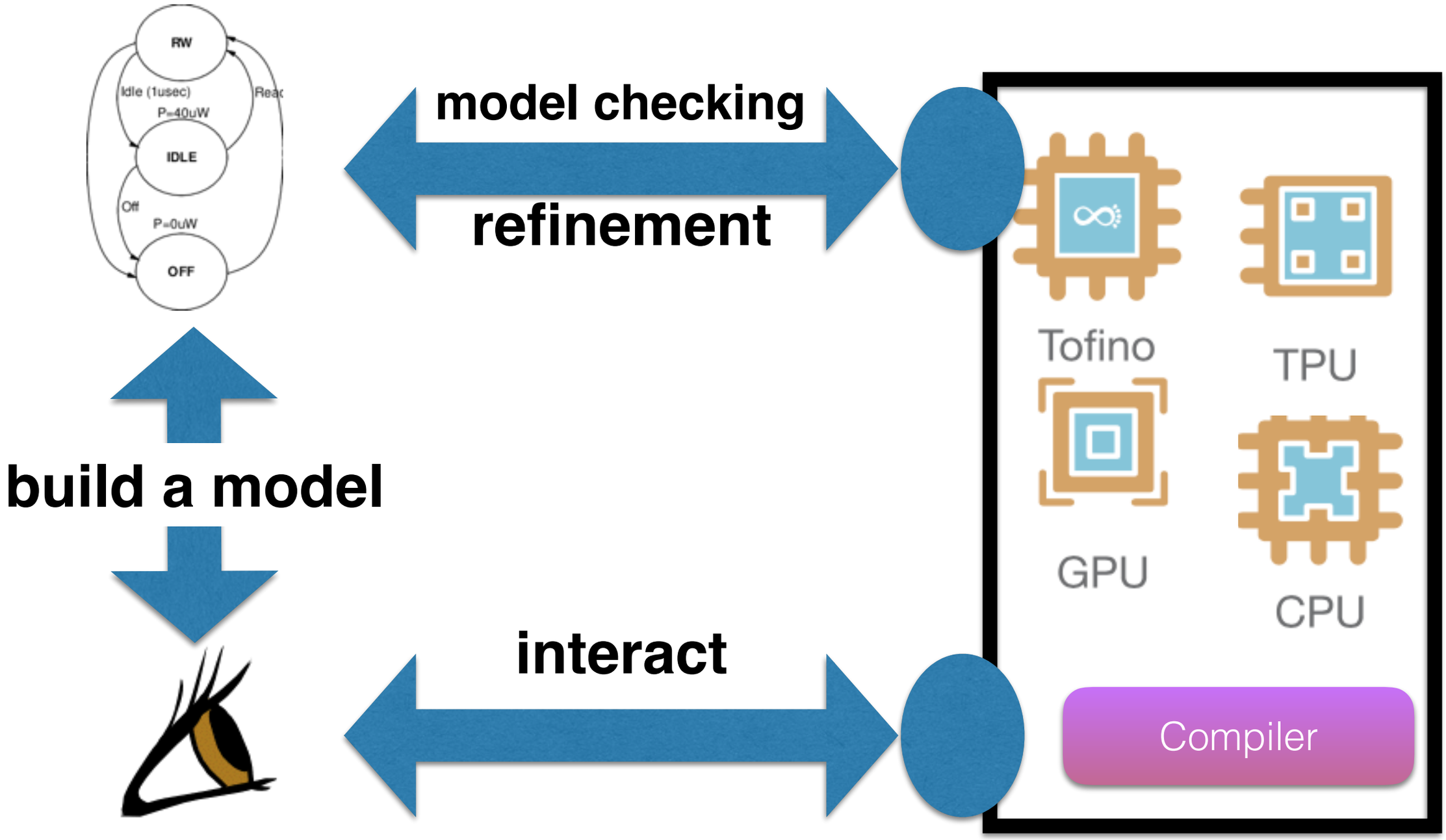
Automated modelling and verification

Source: https://www.barefootnetworks.com/technology/

Automated modelling



Automated modelling



L* algorithm (D.Angluin '87)

Q: $w \in \mathcal{L}?$

A: Y/N

Learner

Q: $\mathcal{L}(H) = \mathcal{L}?$

A: Y / N + counterexample

Teacher

$\mathcal{L}$

H = hypothesis automaton

L* algorithm (D.Angluin '87)

Q: $w \in \mathcal{L}?$

A: Y/N

Learner

Q: $\mathcal{L}(H) = \mathcal{L}?$

A: Y / N + counterexample

Teacher

$\mathcal{L}$

H = hypothesis automaton

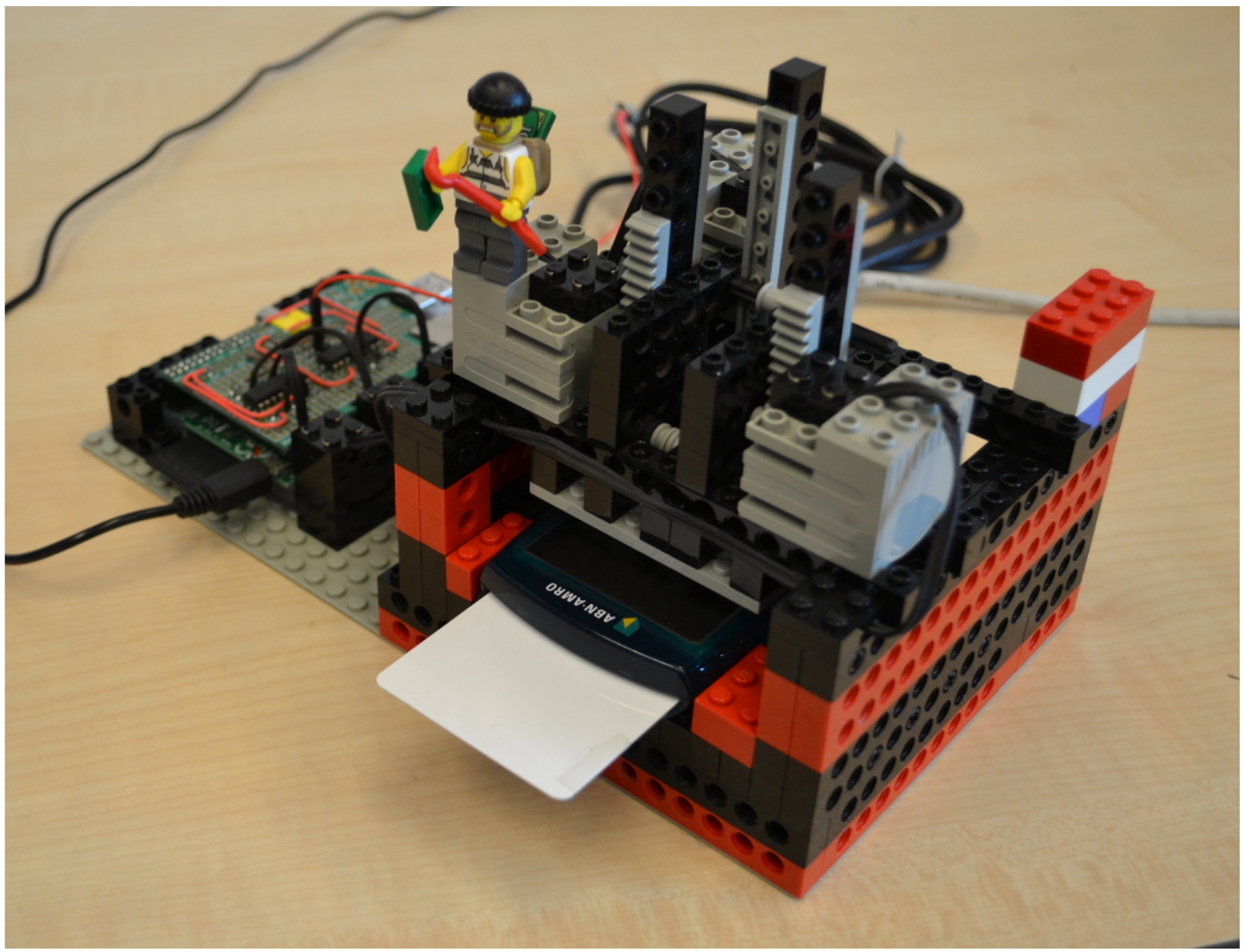
builds

Minimal DFA accepting $\mathcal{L}$

simple is beautiful.

&

Applications : Security, formal verification, …

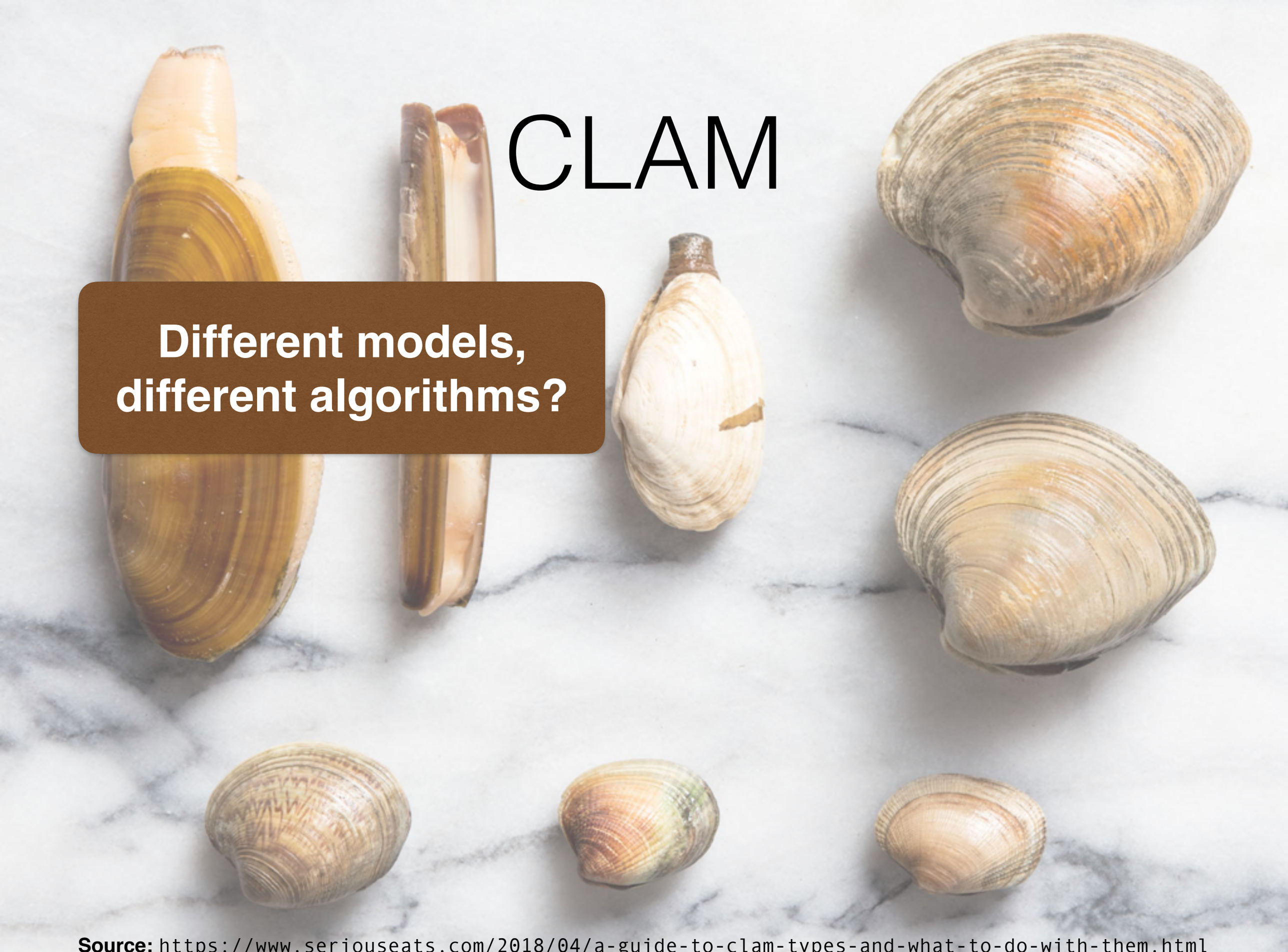


CLAM

Source: https://www.seriouseats.com/2018/04/a-guide-to-clam-types-and-what-to-do-with-them.html

CLAM

Different models, different algorithms?



Source: https://www.seriouseats.com/2018/04/a-guide-to-clam-types-and-what-to-do-with-them.html

CLAM

Different models, different algorithms?

Scalability?

Source: https://www.seriouseats.com/2018/04/a-guide-to-clam-types-and-what-to-do-with-them.html

CLAM

Different models, different algorithms?

Scalability?

Trust?

Source: https://www.seriouseats.com/2018/04/a-guide-to-clam-types-and-what-to-do-with-them.html

CLAM

Different models, different algorithms?

Scalability?

Trust?

Coalgebra to the rescue

Source: https://www.seriouseats.com/2018/04/a-guide-to-clam-types-and-what-to-do-with-them.html

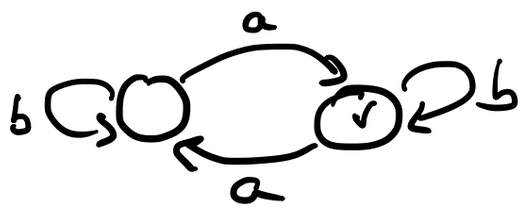
Coalgebraic Learning

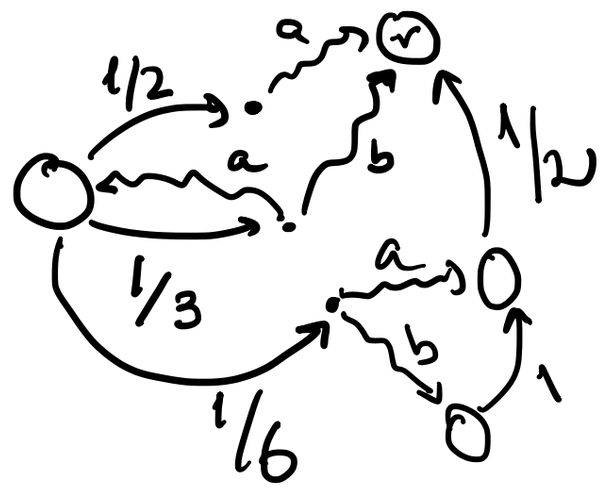
Compiler

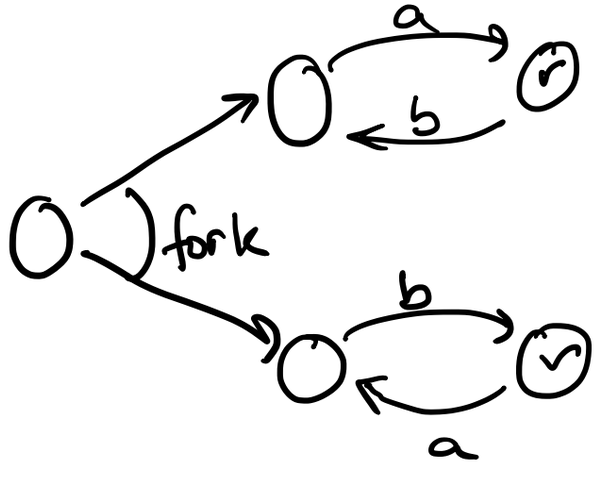
TPU

CPU

Tofino

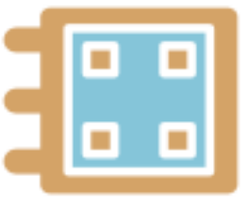






Coalgebraic Learning

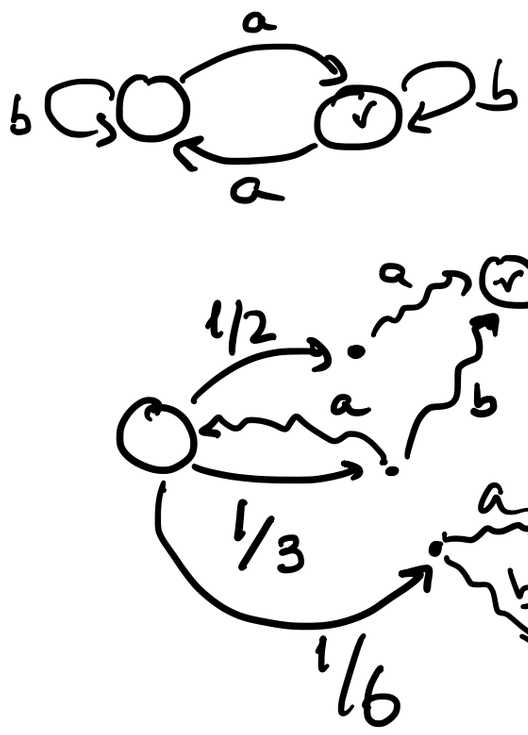
Compiler

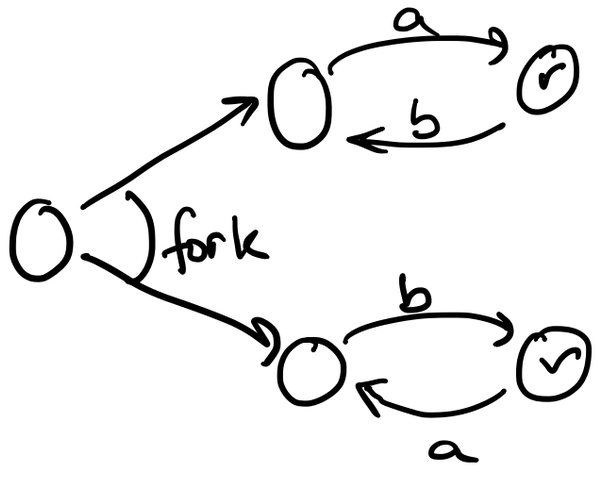


TPU

CPU

Tofino





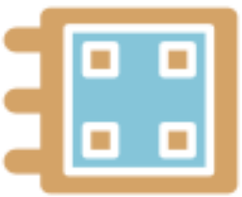
$$X \to FTX$$

Transition structure

Algebraic properties

Coalgebraic Learning

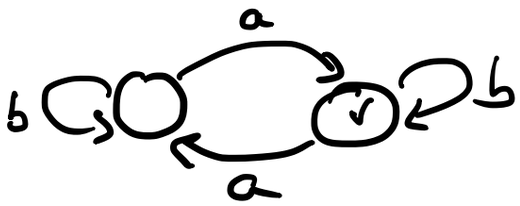
Compiler

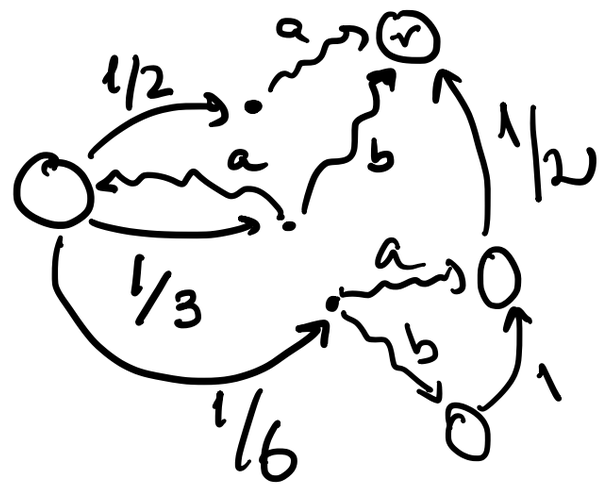


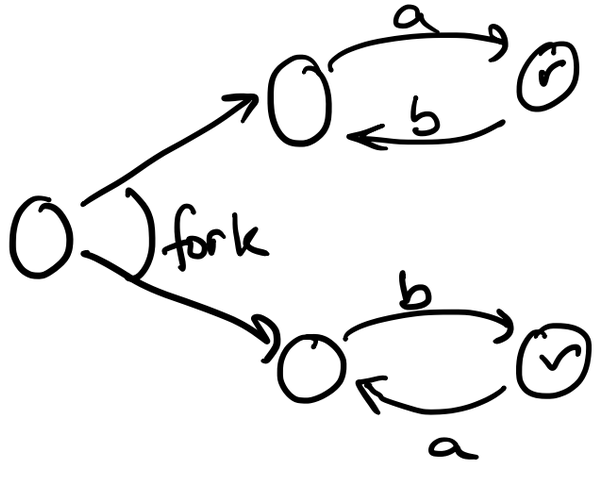
TPU

CPU

Tofino







Coalgebra to the rescue: Abstract L*

$$X \to FTX$$

Transition structure

Algebraic properties

Abstract learning

Abstract observation data structure

Abstract learning

Abstract observation data structure

approximates

Target minimal automaton

$$FQ$$
$$\downarrow \delta_Q$$
$$I \xrightarrow{\mathsf{init}_Q} Q \xrightarrow{\mathsf{out}_Q} Y$$

Abstract learning

Abstract observation data structure

approximates

Target minimal automaton

$$FQ$$
$$\downarrow \delta_Q$$
$$\text{init}_Q \quad Q \quad \text{out}_Q$$
$$I \qquad\qquad Y$$

abstract consistency

Hypothesis automaton

$$FH$$
$$\downarrow \delta_H$$
$$\text{init}_H \quad H \quad \text{out}_H$$
$$I \qquad\qquad Y$$

Abstract learning

Abstract observation data structure

approximates

Target minimal automaton

$$\begin{tikzcd} & FQ \arrow[d, "\delta_Q"] & \\ & Q \arrow[dr, "\mathsf{out}_Q"] & \\ I \arrow[ur, "\mathsf{init}_Q"] & & Y \end{tikzcd}$$

abstract consistency

Hypothesis automaton

$$\begin{tikzcd} & FH \arrow[d, "\delta_H"] & \\ & H \arrow[dr, "\mathsf{out}_H"] & \\ I \arrow[ur, "\mathsf{init}_H"] & & Y \end{tikzcd}$$

General correctness theorem

Guidelines for implementation

Abstract learning

Abstract observation data structure

approximates

Target minimal automaton

$$FQ \xrightarrow{\delta_Q} Q \quad \text{with} \quad \text{init}_Q : I \to Q \quad \text{and} \quad \text{out}_Q : Q \to Y$$

abstract consistency

Hypothesis automaton

$$FH \xrightarrow{\delta_H} H \quad \text{with} \quad \text{init}_H : I \to H \quad \text{and} \quad \text{out}_H : H \to Y$$

General correctness theorem

Guidelines for implementation

CALF: Categorical Automata Learning Framework

Gerco van Heerdt, Matteo Sammartino, Alexandra Silva **(CSL 2017)**

Abstract learning

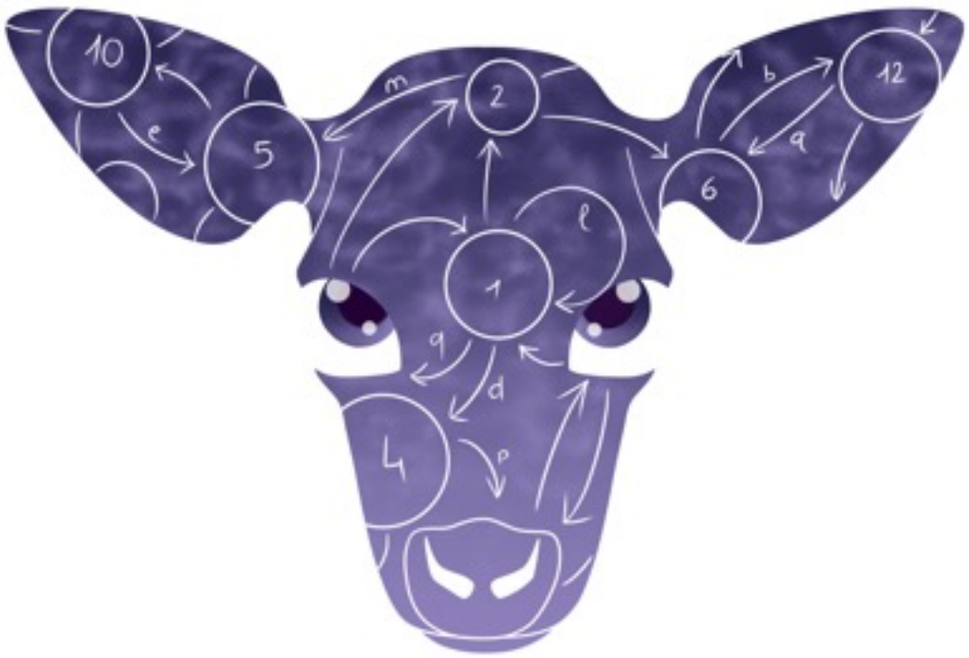
Abstract observation data structure

approximates

Target minimal automaton

$$FQ$$
$$\downarrow \delta_Q$$
$$\text{init}_Q \quad Q \quad \text{out}_Q$$
$$I \qquad\qquad Y$$

abstract consistency



calf-project.org

General correctness theorem

Guidelines for implementation

CALF: Categorical Automata Learning Framework

Gerco van Heerdt, Matteo Sammartino, Alexandra Silva **(CSL 2017)**

Abstract learning

Abstract observation data structure

approximates

Target minimal automaton

$$FQ$$
$$\downarrow \delta_Q$$
$$\text{init}_Q \quad Q \quad \text{out}_Q$$
$$I \qquad\qquad Y$$

abstract consistency

calf-project.org

General correctness theorem

Learning Nominal Automata (POPL '17)

Joshua Moerman, Matteo Sammartino, Alexandra Silva, Bartek Klin, Michal Szynwelski

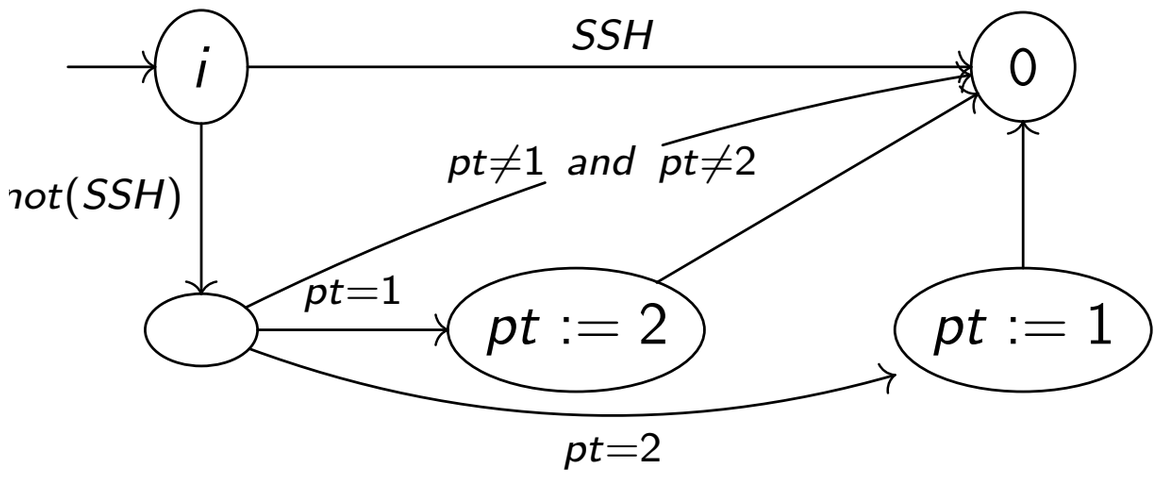
CALF: Categorical Automata Learning Framework

Gerco van Heerdt, Matteo Sammartino, Alexandra Silva **(CSL 2017)**

Automata and Networks

Tofino

NetKat

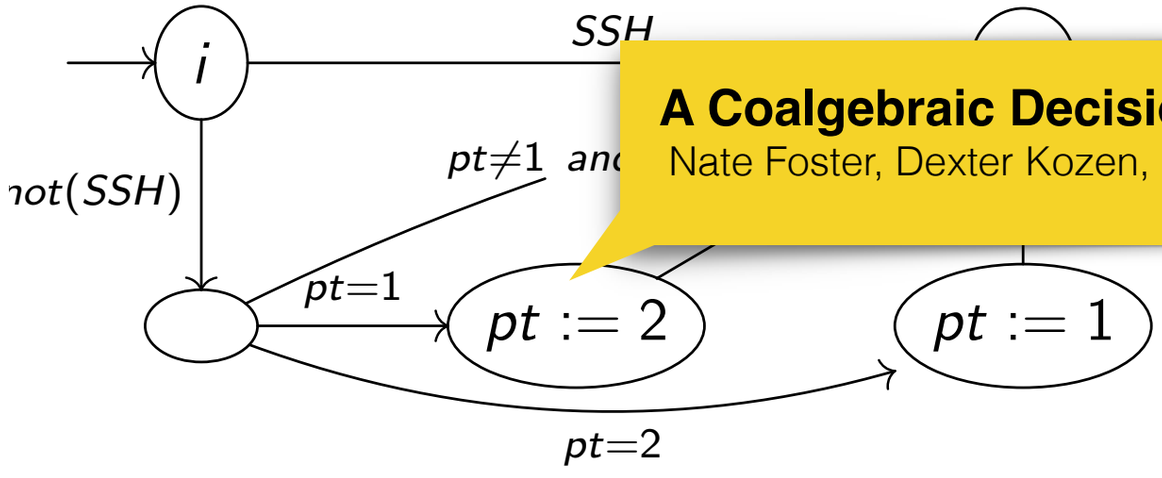


Pattern	Action
typ=SSH	Drop
port=1	Output 2
port=2	Output 1
*	Drop

Automata and Networks

Tofino

NetKat



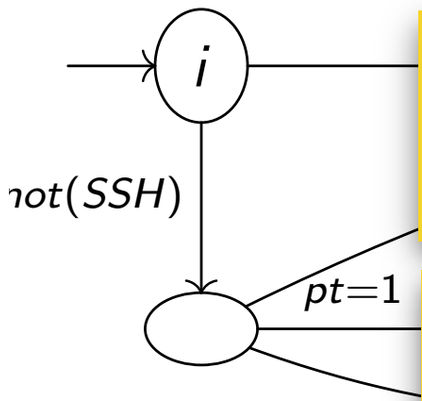
A Coalgebraic Decision Procedure for NetKAT (POPL ’15)

Nate Foster, Dexter Kozen, Matthew Milano, Alexandra Silva, Laure Thompson

port=2	Output 1
*	Drop

Automata and Networks

ProbNetKat



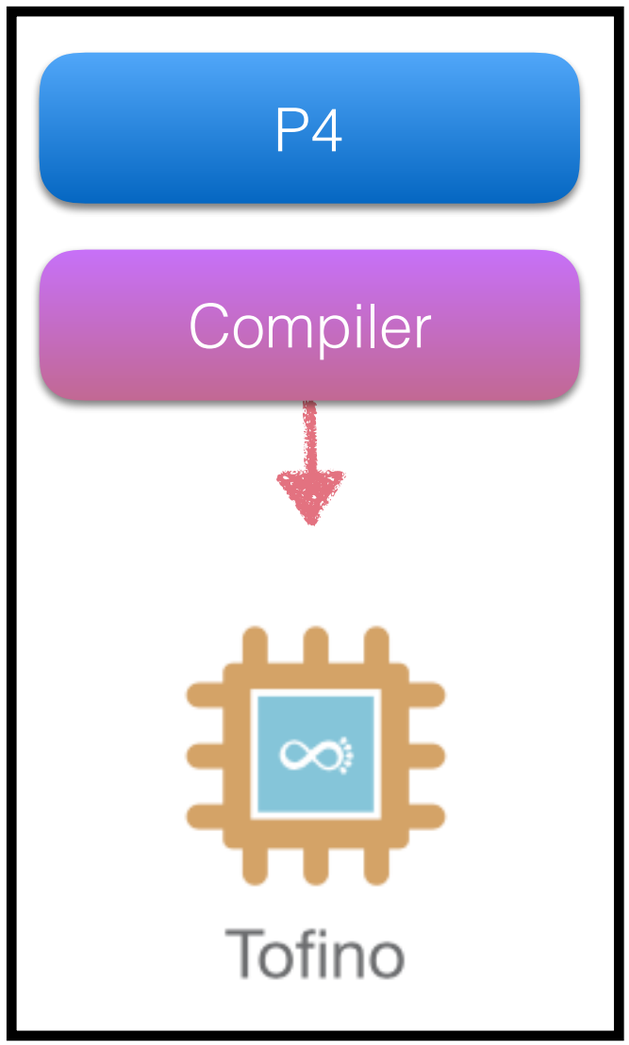
Cantor meets Scott: semantic foundations for probabilistic networks (POPL' 17)

Steffen Smolka, Praveen Kumar, Nate Foster, Dexter Kozen, Alexandra Silva

Probabilistic NetKAT (ESOP 2016)

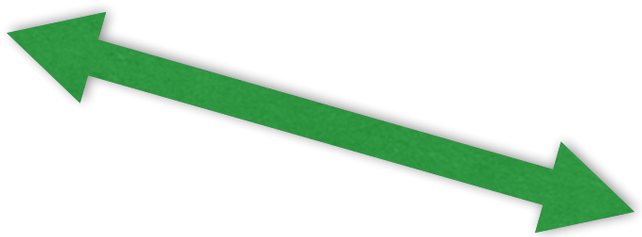
Nate Foster, Dexter Kozen, Konstantinos Mamouras, Mark Reitblatt, Alexandra Silva

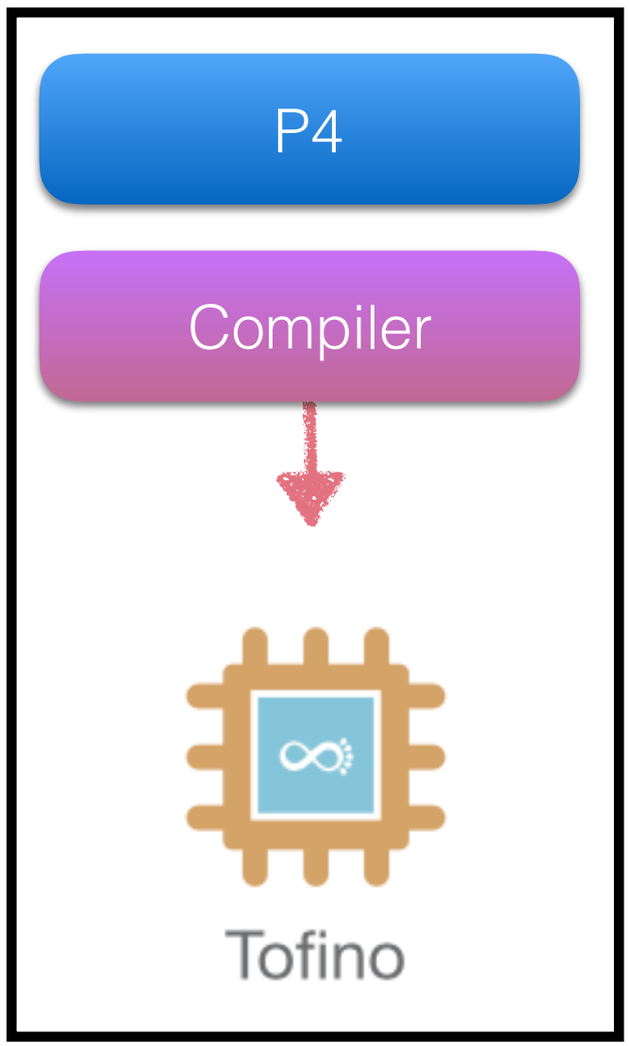
The Horizon

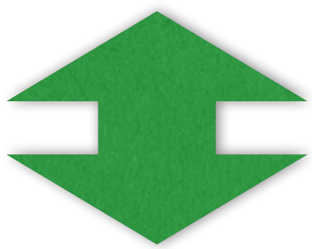


The Horizon

NetKat



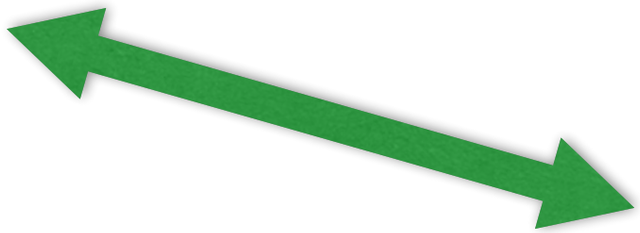


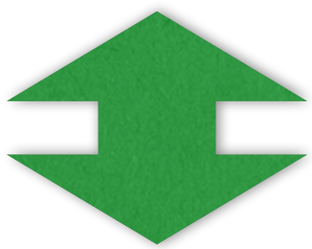


Automaton

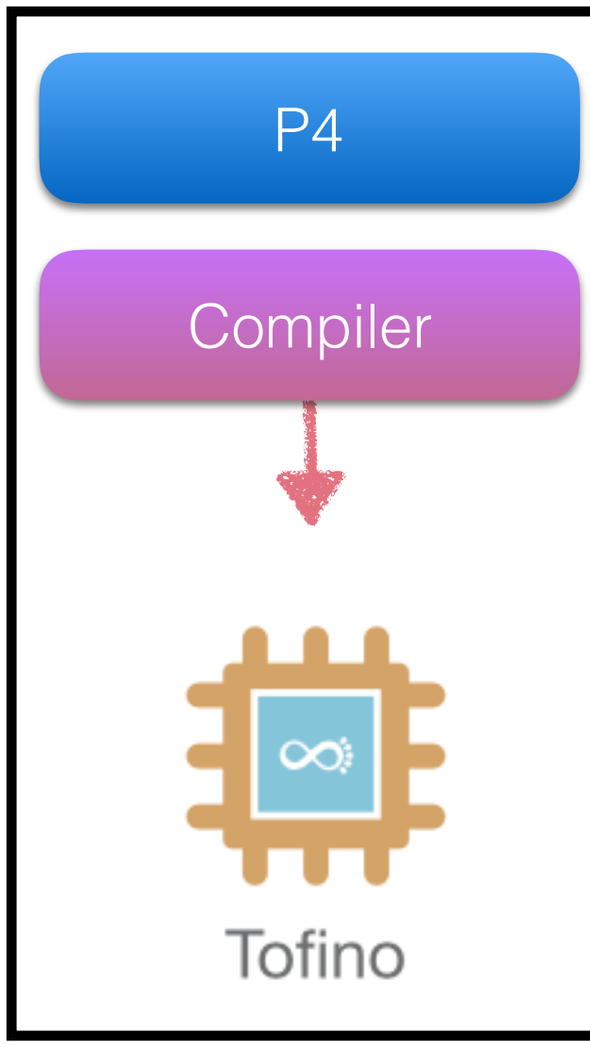
The Horizon

NetKat



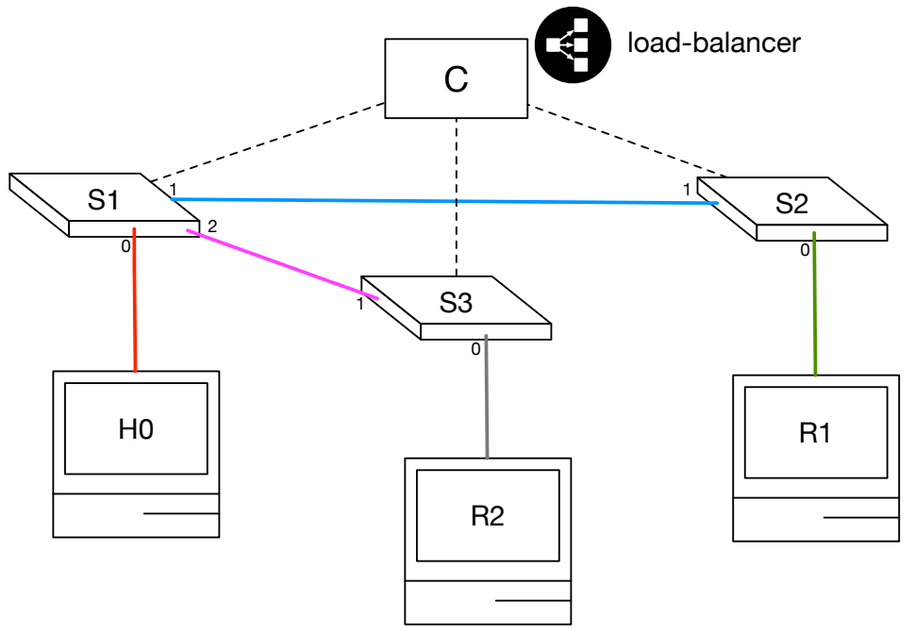


Automaton



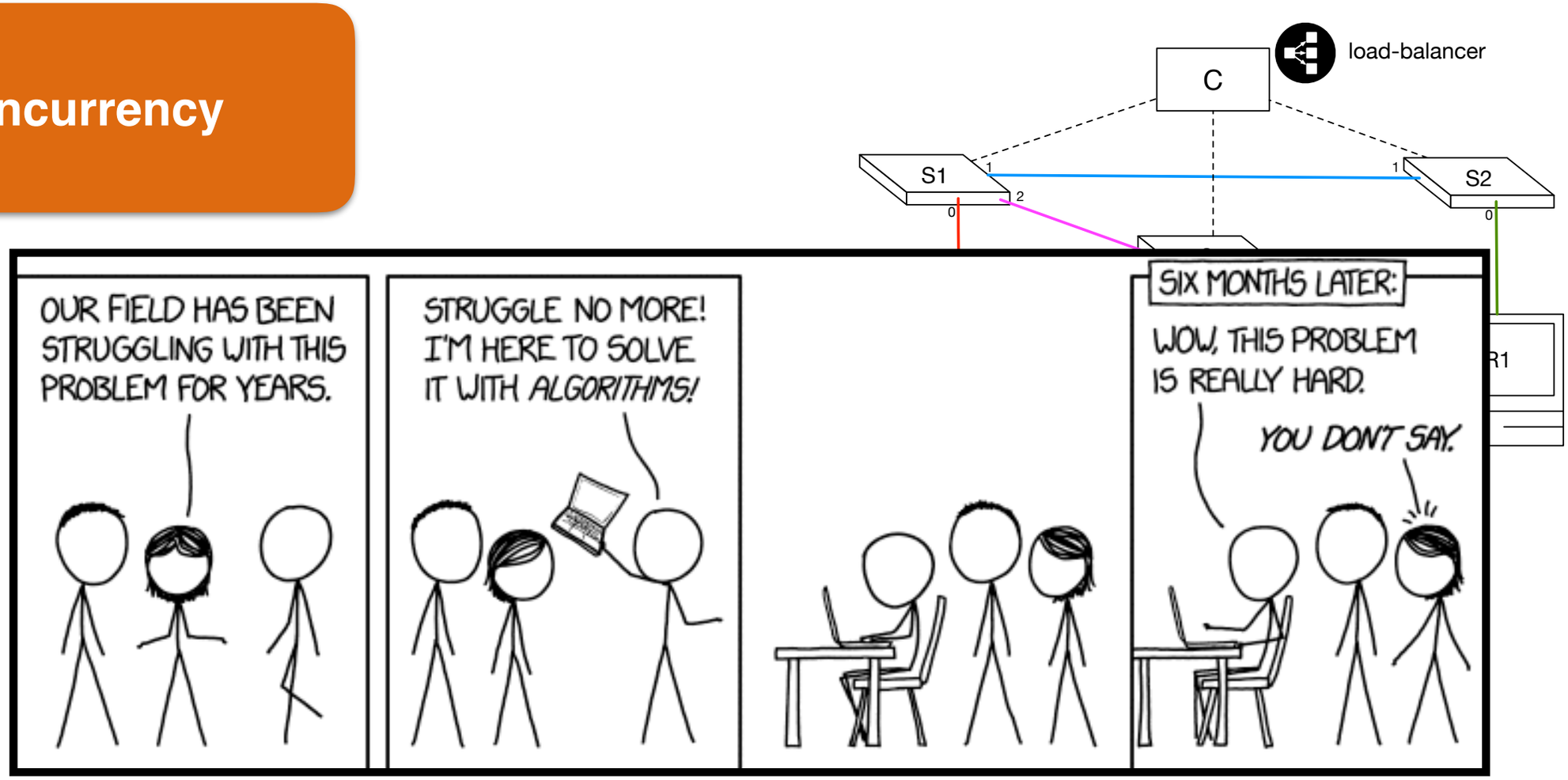
The Horizon

Concurrency



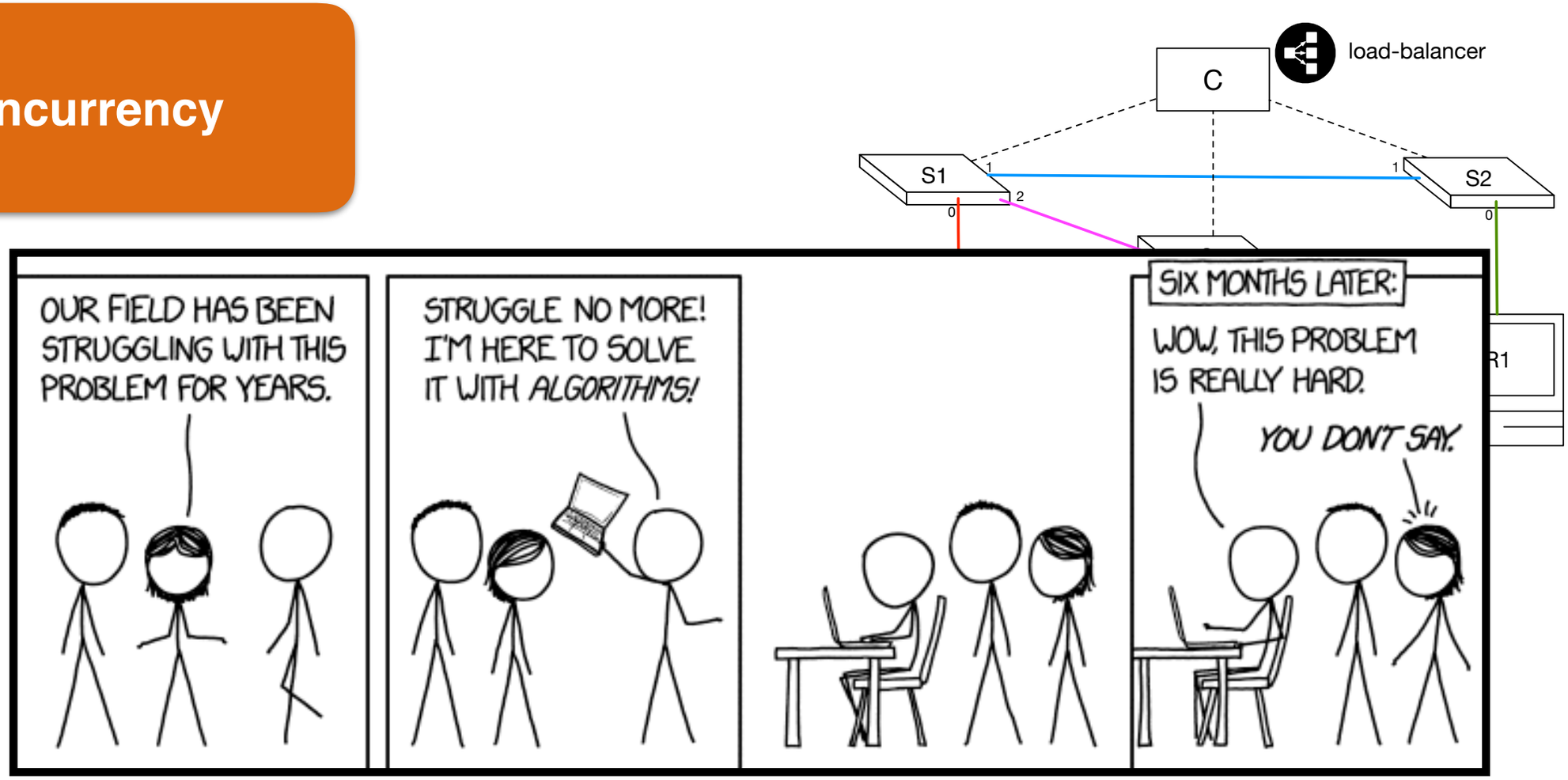
The Horizon

Concurrency



The Horizon

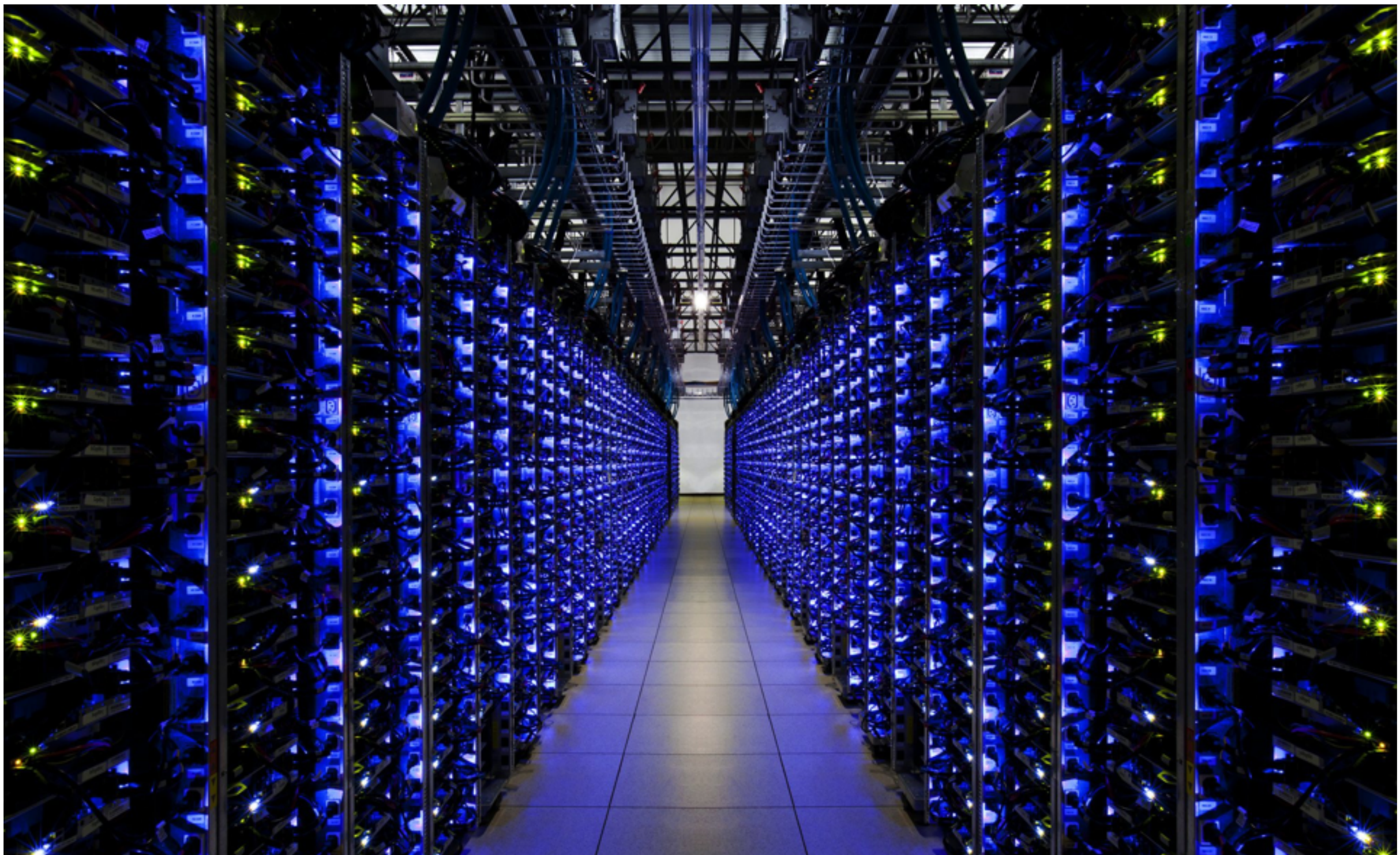
Concurrency



GoNeCo

coneco-project.org

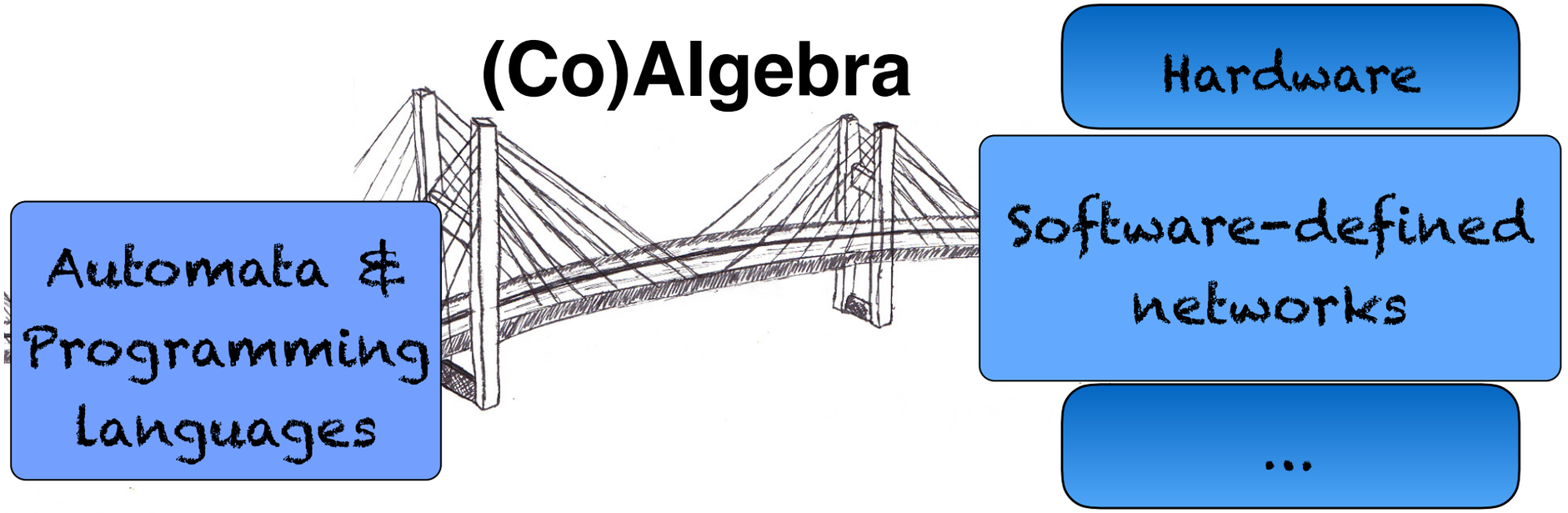
The Horizon



The Horizon

McNetKAT
Scalable Verification of Probabilistic Networks

Conclusions



Thanks

Thanks

Cornell University

Radboud University

Thanks

FCT
Fundação para a Ciência e a Tecnologia
MINISTÉRIO DA CIÊNCIA, TECNOLOGIA E ENSINO SUPERIOR

NWO
Netherlands Organisation for Scientific Research

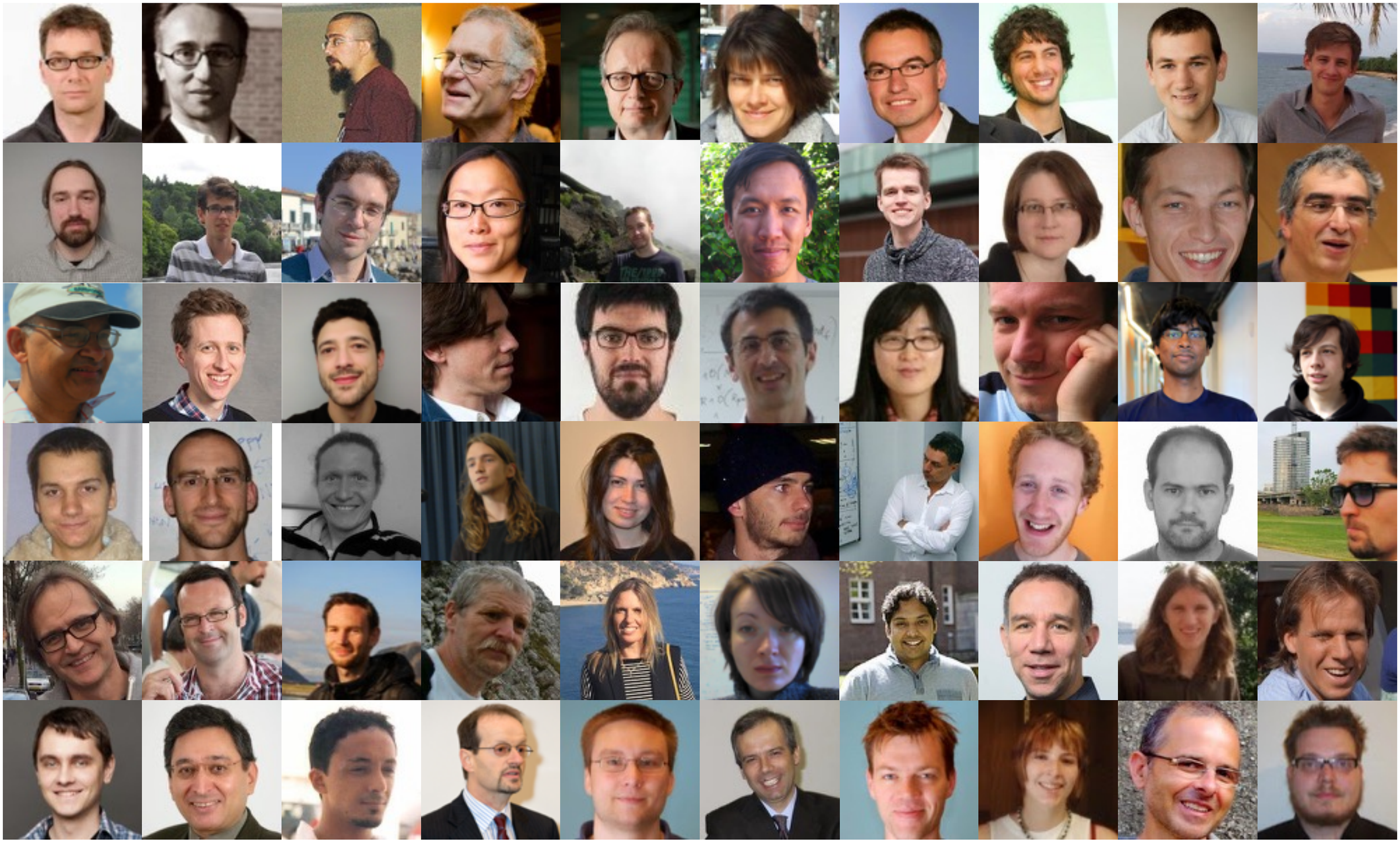
erc
European Research Council
Established by the European Commission

The Leverhulme Trust

eTSS

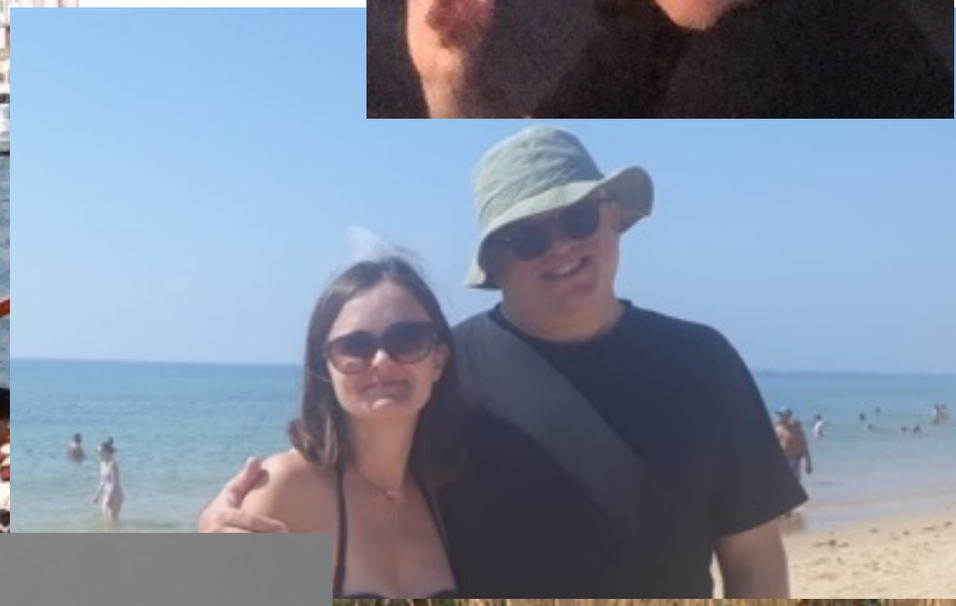
EPSRC

Thanks



Thanks

Thanks



Dedication

Dedication

That's all Folks!