Quality Assurance of Cyber-Physical Systems

Mathematical Metatheory, Machine Learning and Automated Driving

物理情報システム研究の新地平

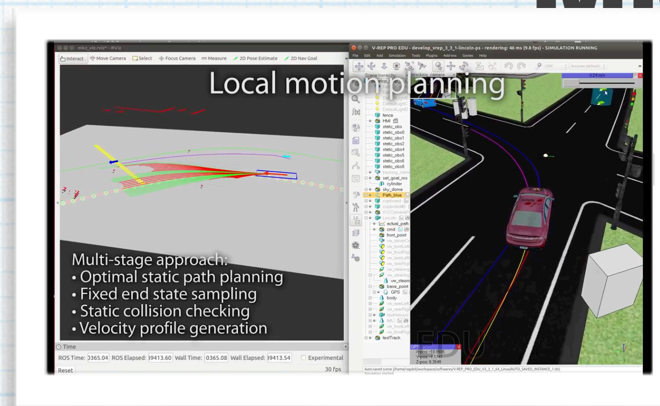
自動運転や機械学習をも包括する数学的基盤

Slides available:
bit.ly/2SdJpIY

Ichiro Hasuo　蓮尾 一郎

National Institute of Informatics, SOKENDAI
ERATO HASUO Metamathematics for Systems Design Project

On ERATO MMSD



- JST ERATO Project, 2016/10-2022/03
- Our goal:
  formal methods for cyber-physical systems (CPS)
  - Extend formal methods, from software to CPS
  - Safety, reliability, V&V (Verification & Validation).
    "Check if a system behaves as expected"
  - Automated driving as a strategic target domain.
    Collaboration with U Waterloo: www.autonomoose.net
- Our principle: broaden the realm of CPS research
  - Theory:
    abstract mathematical metatheory
    ➜ scale out to diverse applications
  - Practice: real-world systems (not only toy examples)

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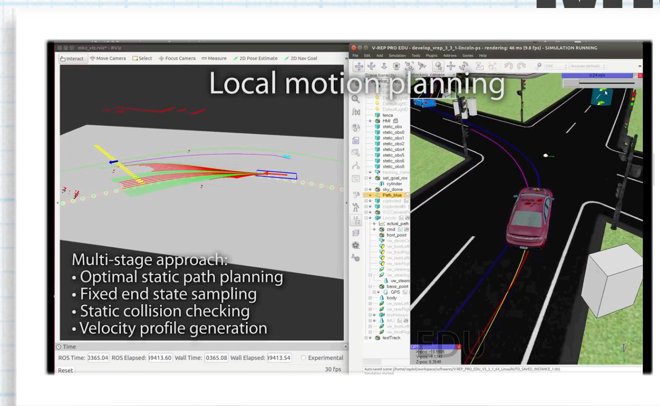

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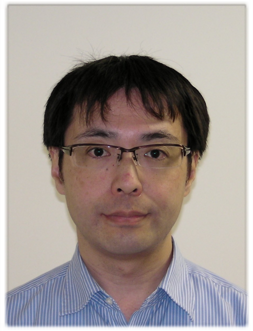
Our Organization

International and multi-disciplinary. “creative chaos”

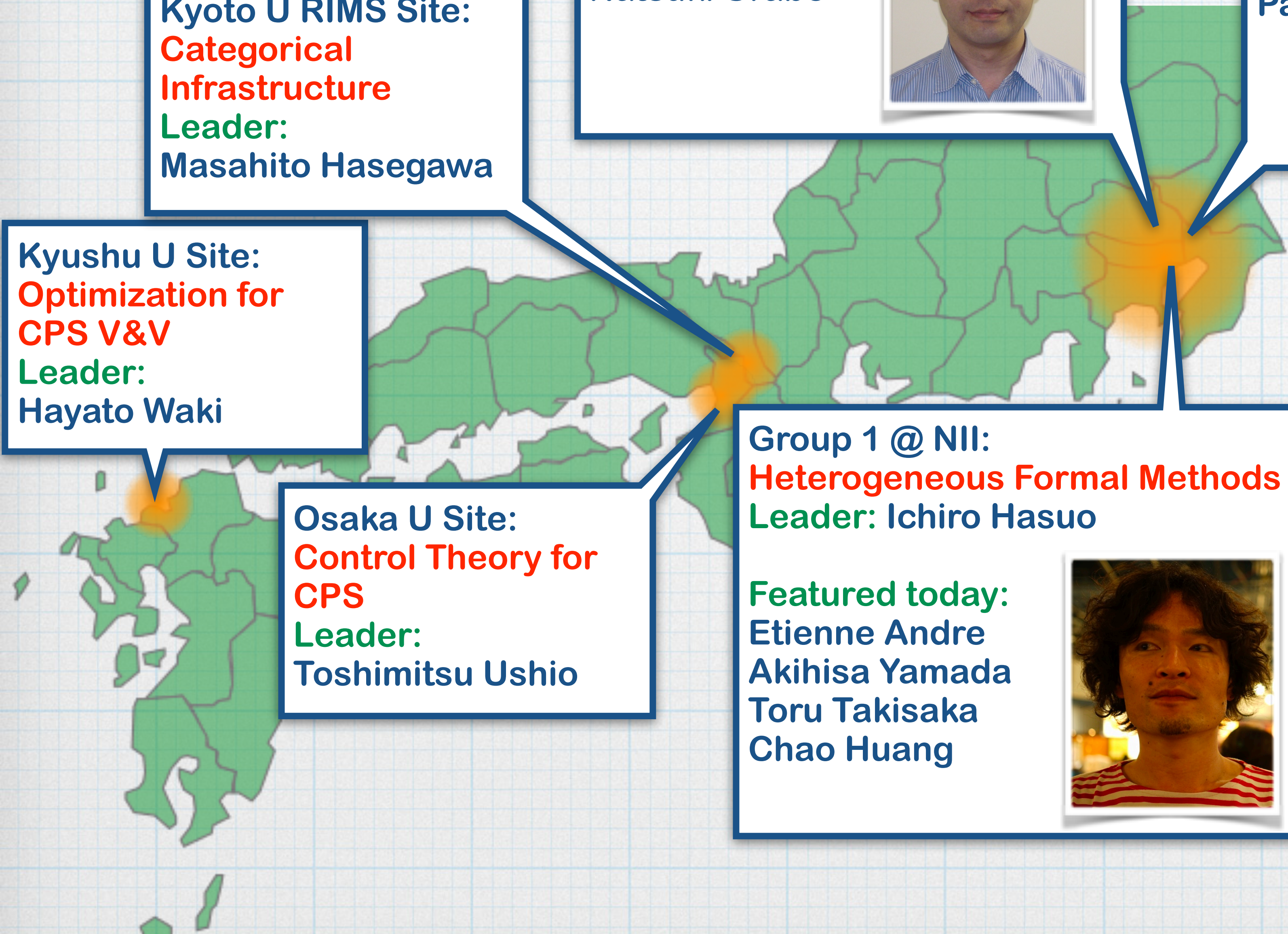
Group 0 @ NII:
Metatheoretical Integration
Leader: Shin-ya Katsumata

Featured today:
Kenta Cho
Clovis Eberhart
Natsuki Urabe



Group 3 @ NII:
Formal Methods and Intelligence
Leader: Fuyuki Ishikawa

Featured today:
Masaki Waga
Paolo Arcaini



Kyoto U RIMS Site:
Categorical Infrastructure
Leader:
Masahito Hasegawa

Kyushu U Site:
Optimization for CPS V&V
Leader:
Hayato Waki

Osaka U Site:
Control Theory for CPS
Leader:
Toshimitsu Ushio

Group 1 @ NII:
Heterogeneous Formal Methods
Leader: Ichiro Hasuo

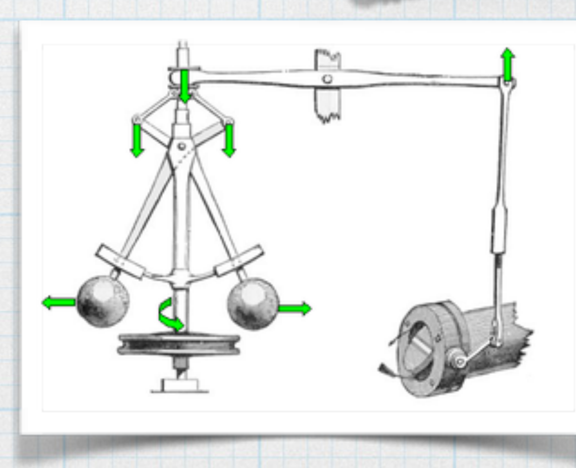
Featured today:
Etienne Andre
Akihisa Yamada
Toru Takisaka
Chao Huang

Group 2 @ U Waterloo:
Formal Methods in Industry
Leader: Krzysztof Czarnecki

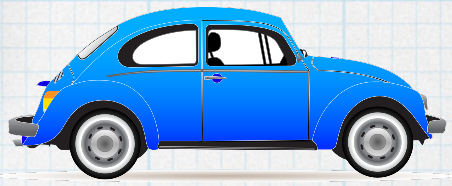
Cyber-Physical Systems : Control Theory and Formal Methods/Software Science

- Cyber-Physical System (CPS)
  - "A mechanism that is controlled or monitored by computer-based algorithms, tightly integrated with the Internet and its users" (Wikipedia)
  - Physical plant (continuous) + Digital control (discrete)
  - In US: NSF Key Area of Research (2006-)
- Formal methods: Logical proofs for "correctness" of (discrete) programs
  - Model checking [Pnueli, Clarke, Emerson, Sifakis, ...]
  - Theorem Proving (Coq, Agda, ...) [Milner, Coquand, Leroy, Voevodsky, ...]

- Control Theory: Analysis of continuous dynamics
  - Stability, Lyapunov function, ...
- Their similarity is widely recognized
  - Toru Takisaka's talk on martingale synthesis for probabilistic programs (later)



CPS Research, So Far (the V&V Aspect)



CPS
(esp. hybrid systems)

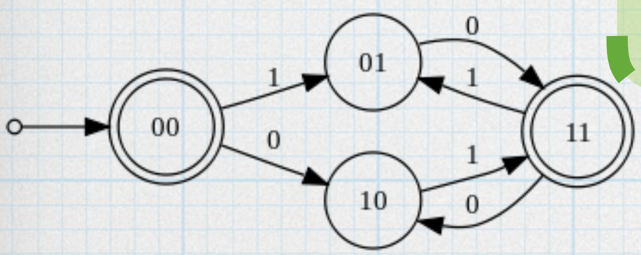
Analysis

Formal Methods

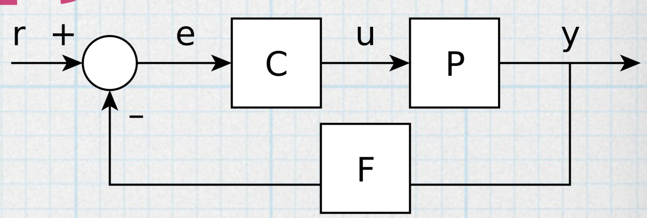
Collaboration

Control Theory

$\Box(p \Rightarrow \Diamond q)$



$x' = f(x, u)$



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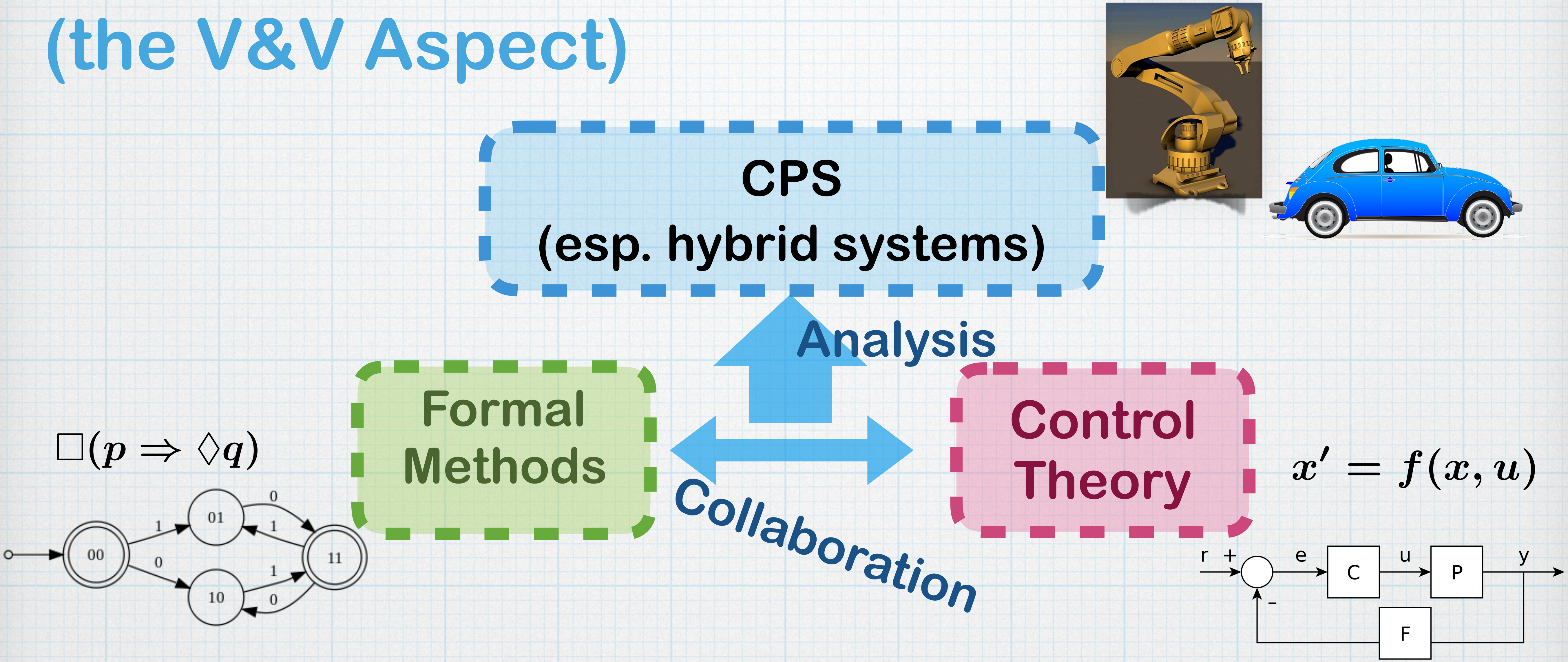
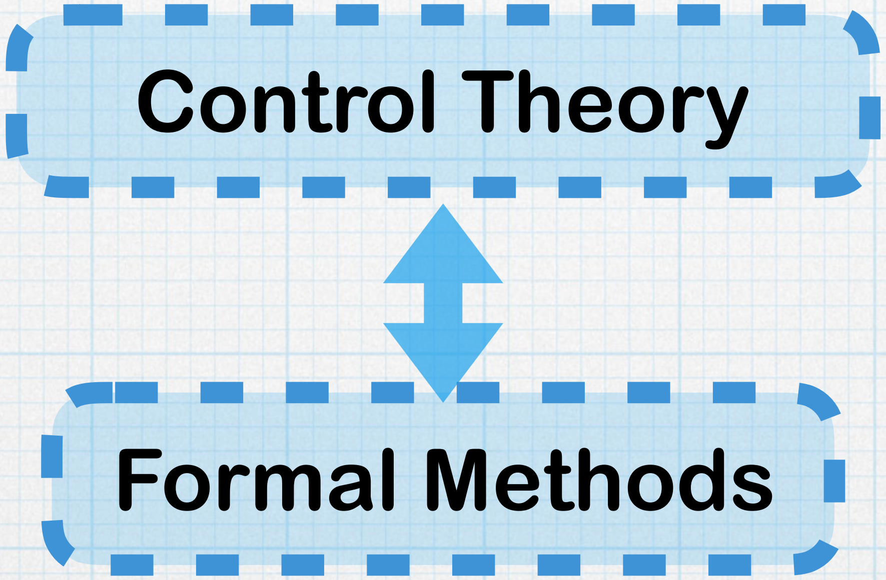


- Problem: scalability, esp. for real-world CPSs
  - Require complete understanding of a white-box model
  - Insist on being absolutely sound and correct
  - Little tolerance to uncertainty and noise
    ➜ don't get along with statistical machine learning

CPS Research: Our Comprehensive Approach



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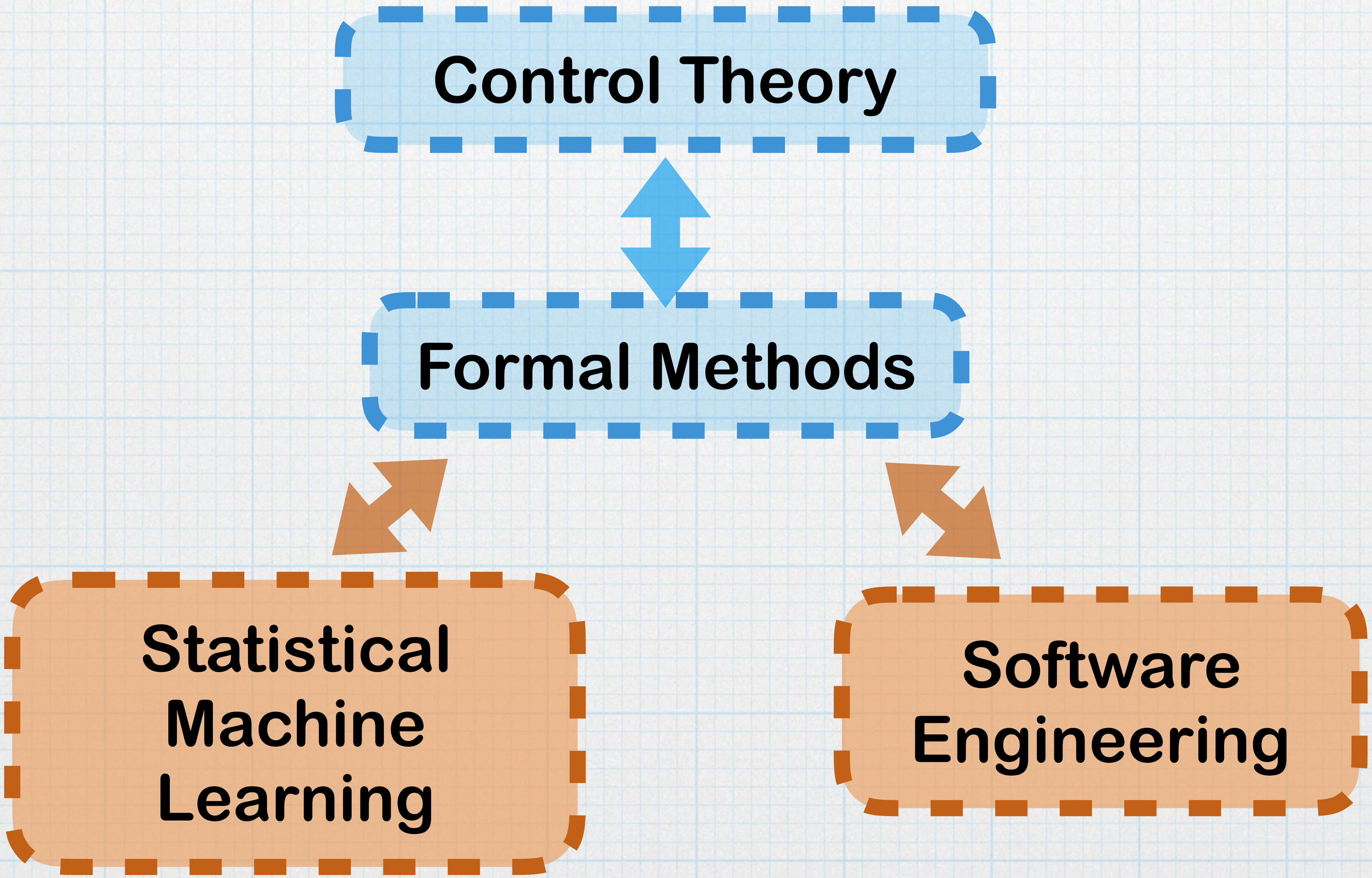

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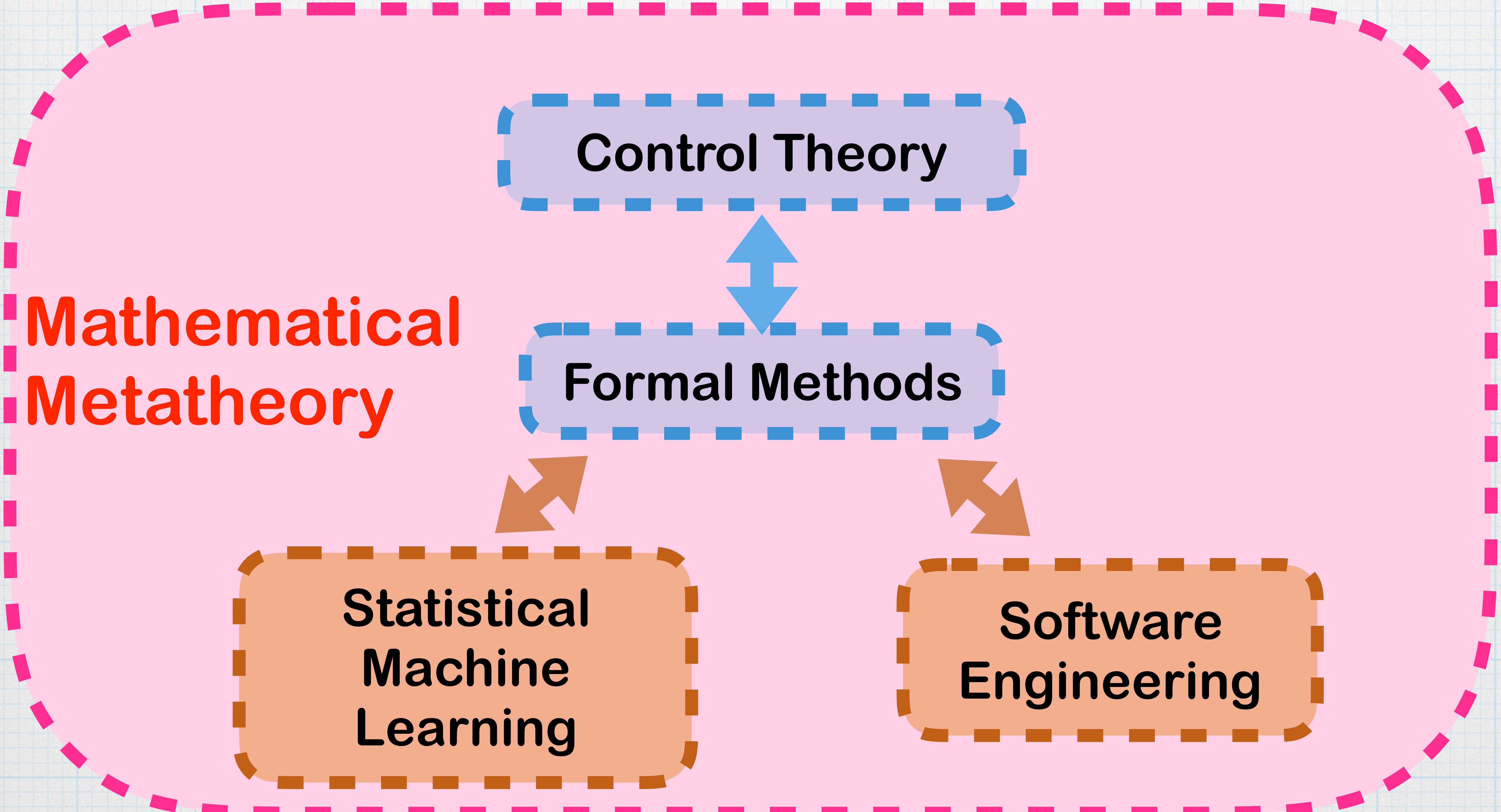

Bidirectional Collaboration with Statistical Machine Learning

* Statistical ML	Inductive (learn from data)	Uncertainty (data is noisy)	(Typically) Black Box
* Formal Methods, Control Th.	Deductive (Infer from absolute axioms)	Mathematical & Logical Rigor	White Box

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Formal Methods Control Theory

Statistical ML

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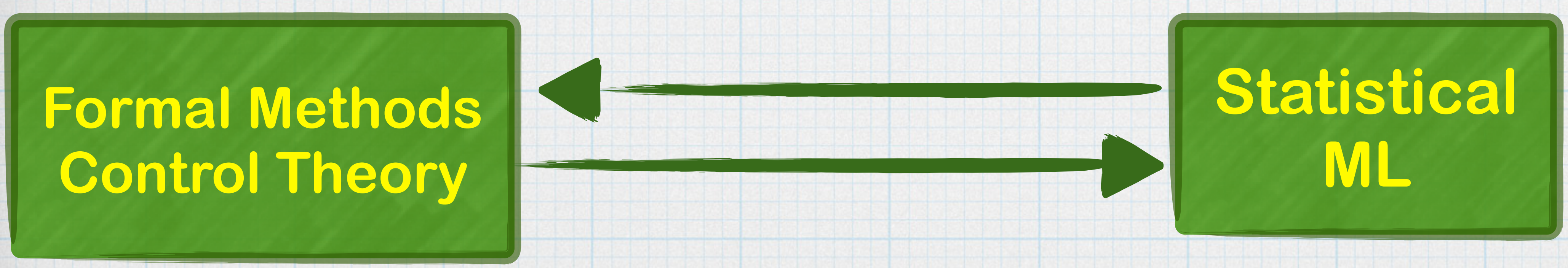

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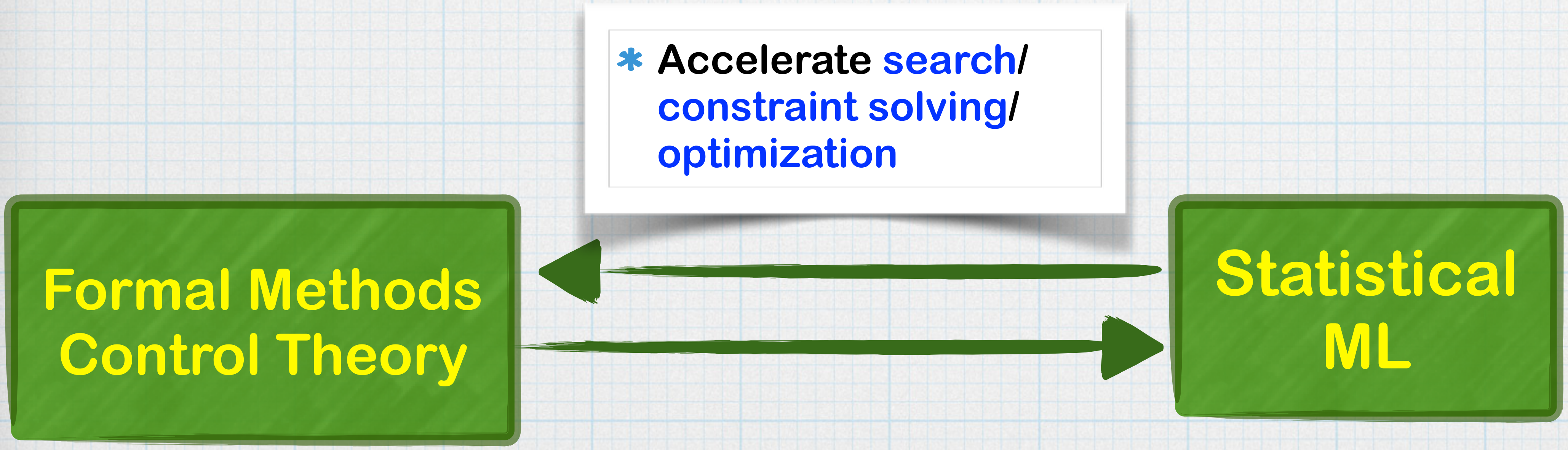

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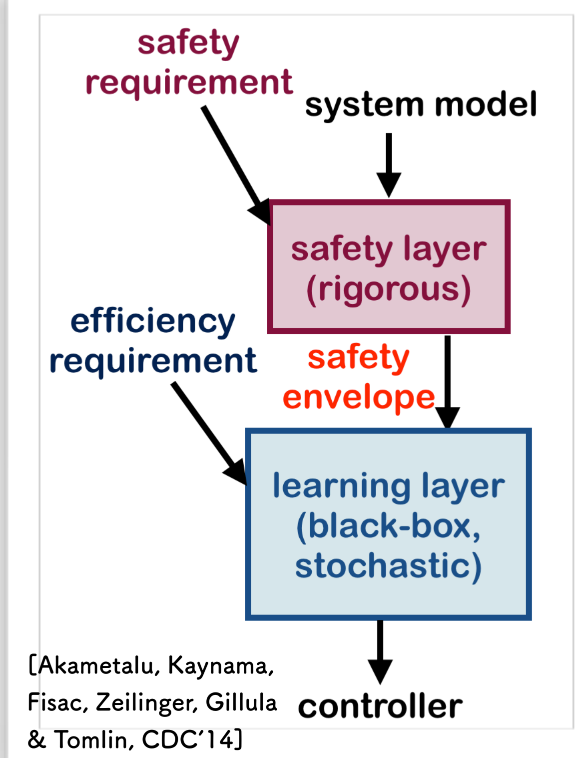
* Accelerate search/ constraint solving/ optimization

Formal Methods Control Theory ⇄ **Statistical ML**

* Acknowledge that ML components are unreliable
* Wrap them with "safety envelopes,"
* within which ML optimizes



Key: system-level architecture for collaboration between logic and ML. Separation of concerns

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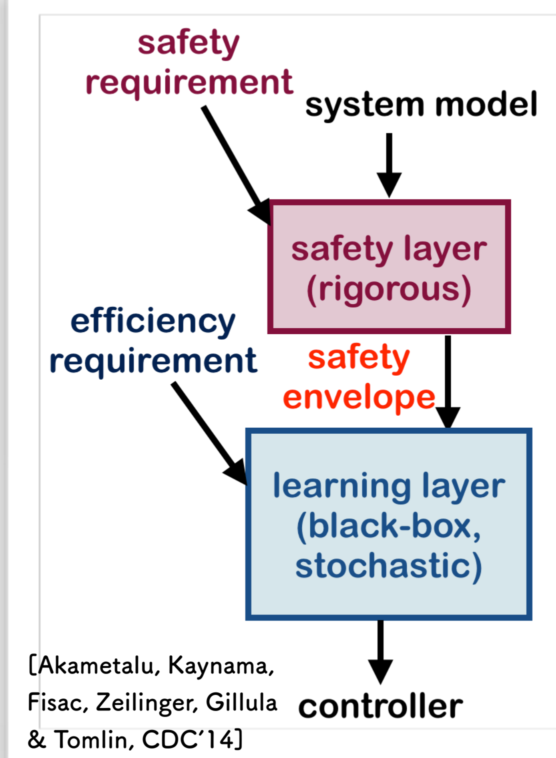
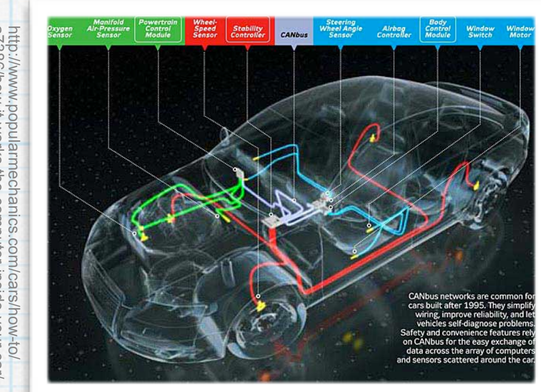


Software Engineering and Empirical Application of Formal Methods and Control Theory



http://www.popularmechanics.com/cars/how-to/a7386/how-it-works-the-computer-inside-your-car/

- Challenges in industrial application
  - Scalability: real systems are complex
  - Need complete white-box models
    - Unrealistic. Components from suppliers, neural nets, …
  - Industry practitioners need not appreciate rigorous proofs
    - How do we check axioms (= environmental assumptions)?

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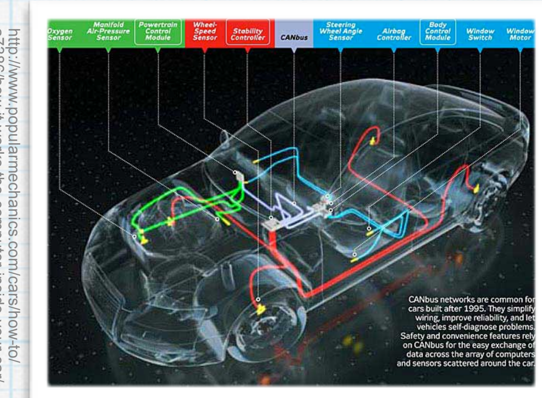

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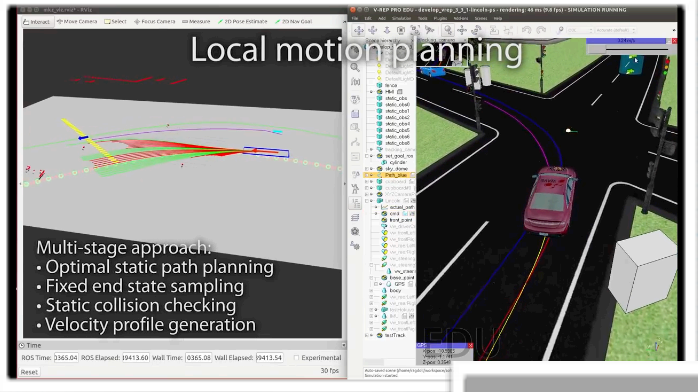
- ➜ We focus on supporting empirical quality assurance methods (i.e. testing)
  - What software engineering has been doing for years
  - Testing, runtime verification, …
  - Ample use of deductive techniques from formal methods
    - Examples: from specifications to score functions, optimize test cases, …
    - Talks by Etienne Andre, Masaki Waga, Paolo Arcaini

Exit Strategy (in Application)



- Outlets
  - Industry collaboration: a few companies
  - Automated Driving Vehicle Project "Autonomoose" (U Waterloo). (Mostly) nonproprietary software stack for automated driving

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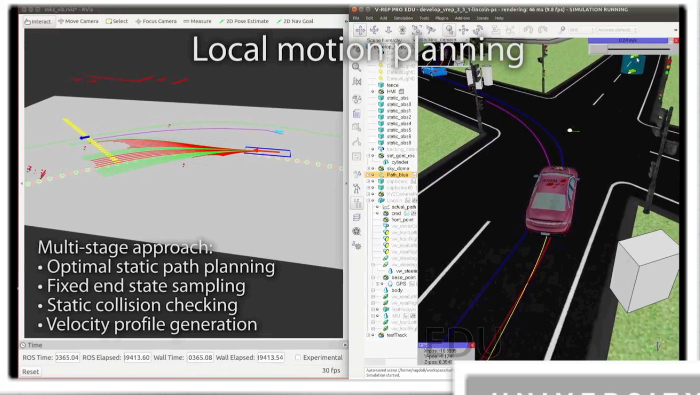

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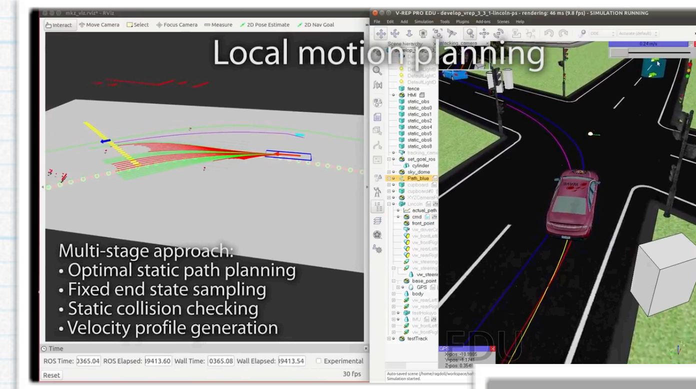

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- **Goal 1**: our advanced quality assurance techniques, put to real use
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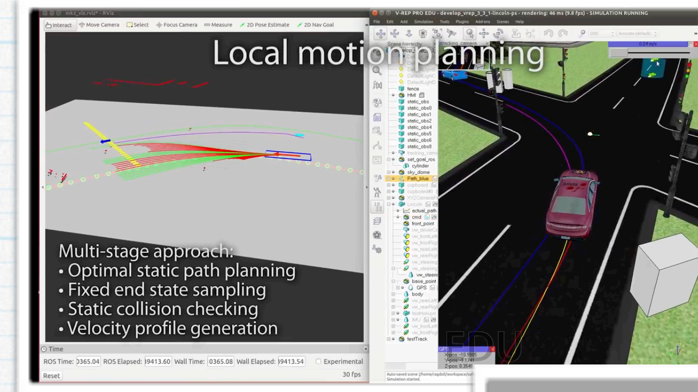

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* Goal 2: offer software platform for developing, verifying and validating automated driving software
  * For industry and academia
  * Perception ➜ Object Recognition ➜ Path Planning ➜ Path Tracing, + Simulation + Testing, V&V
  * Improvement of each component + Interface between components, DSL (domain specific language)

    ➜ the whole framework
  * Our unique strength: advanced V&V techniques + their theoretical foundation + programming language theory

Strategic contribution areas

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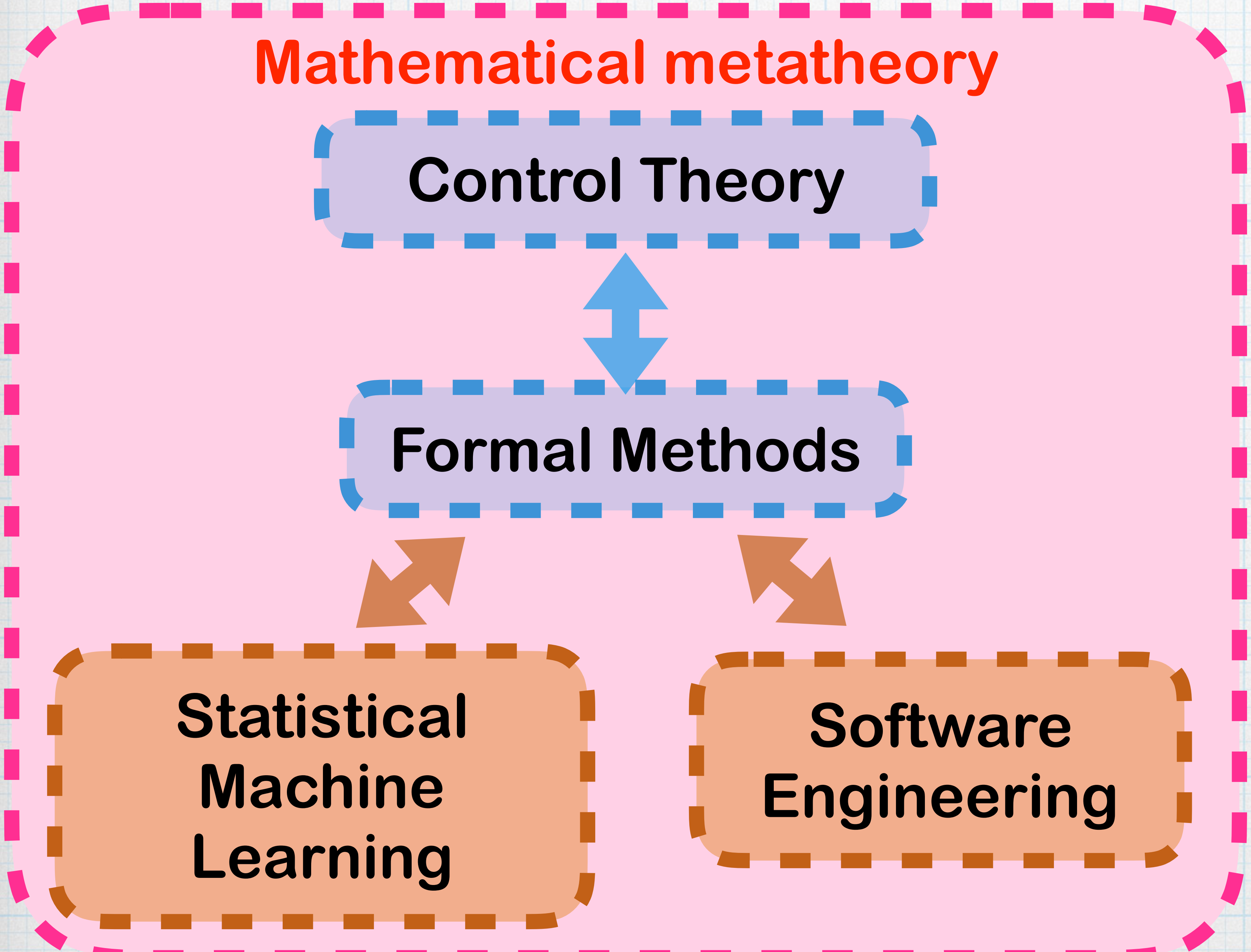

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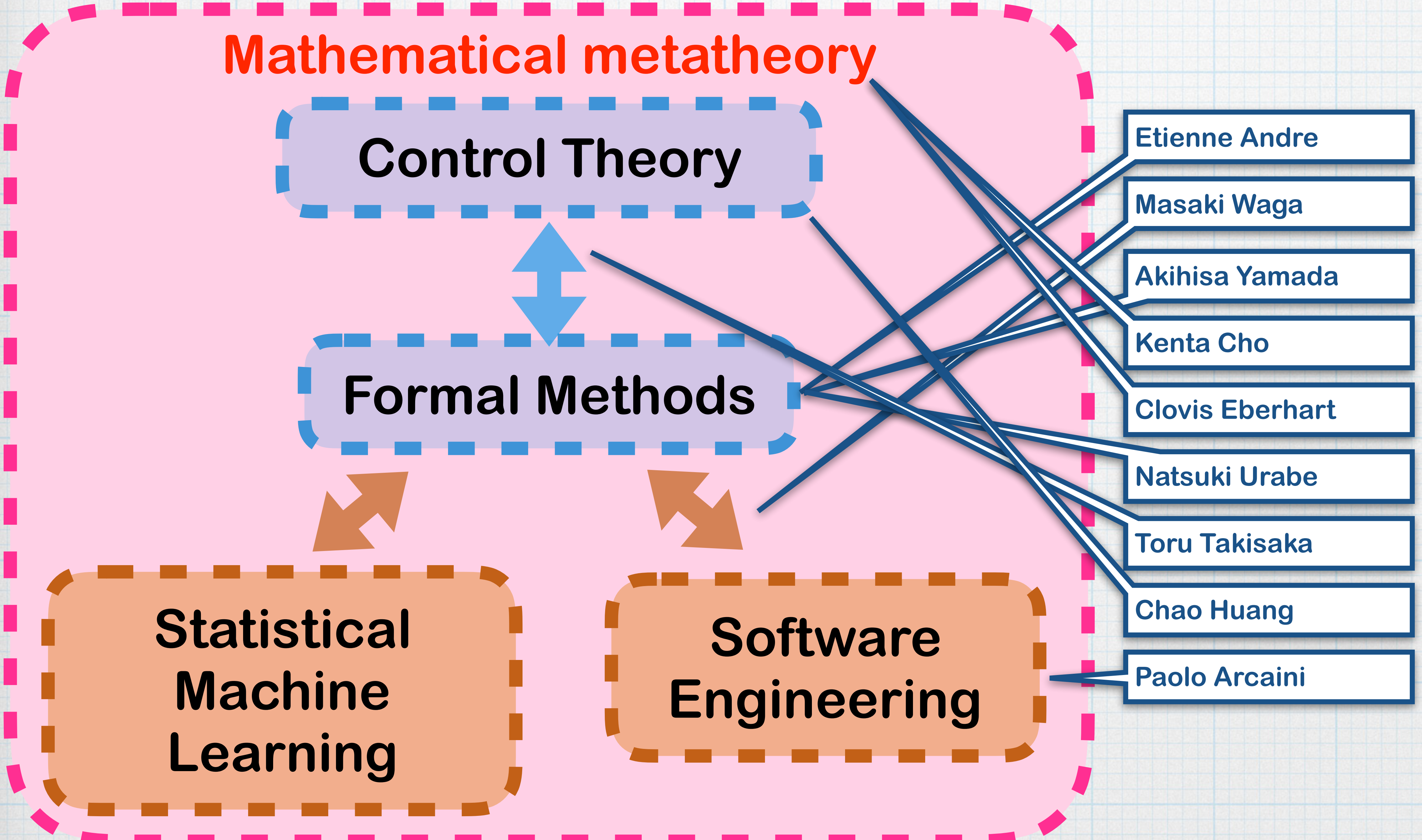

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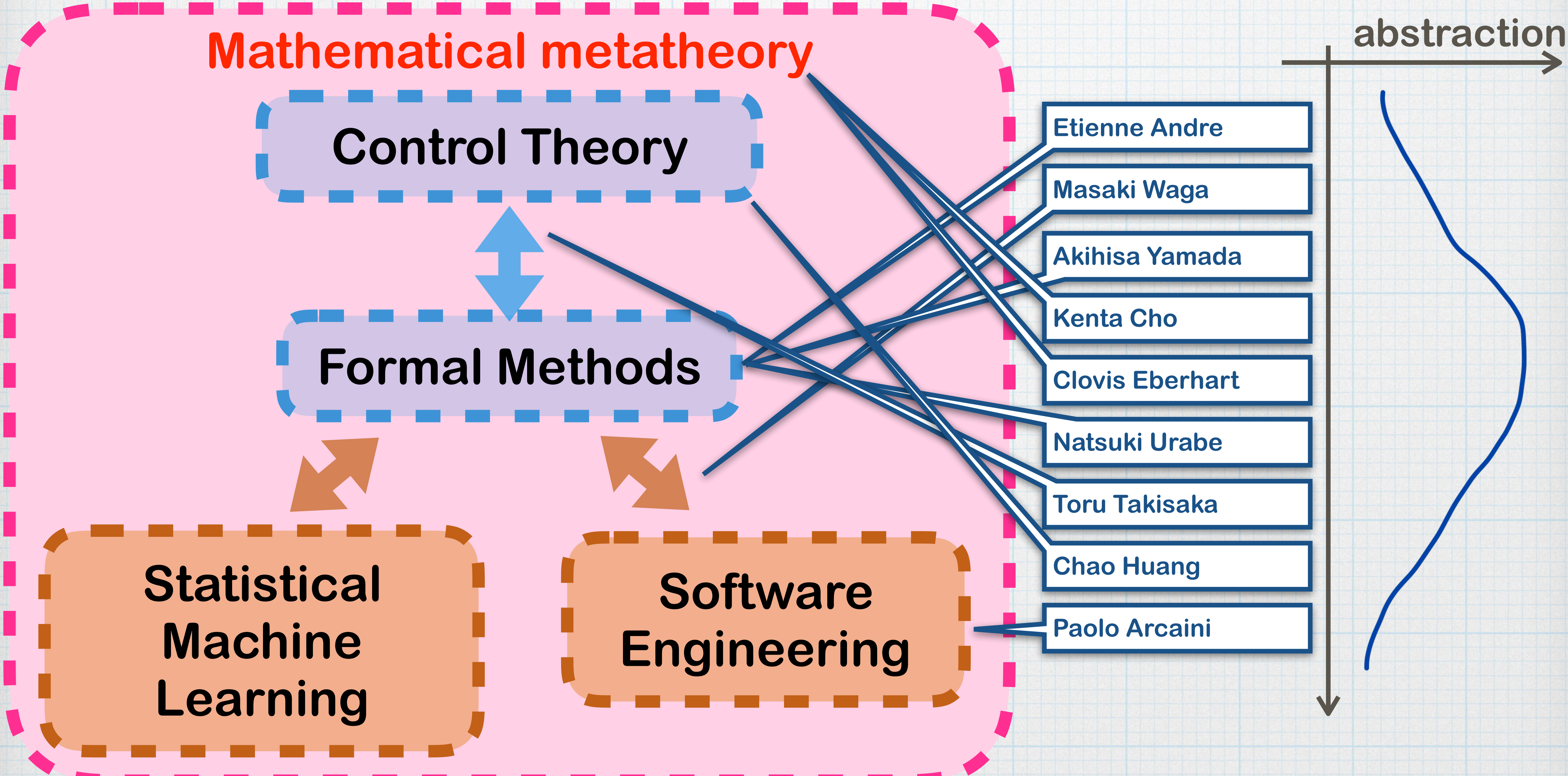

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