Verification and Validation in Cyber-Physical Systems: Research Challenges and a Way Forward

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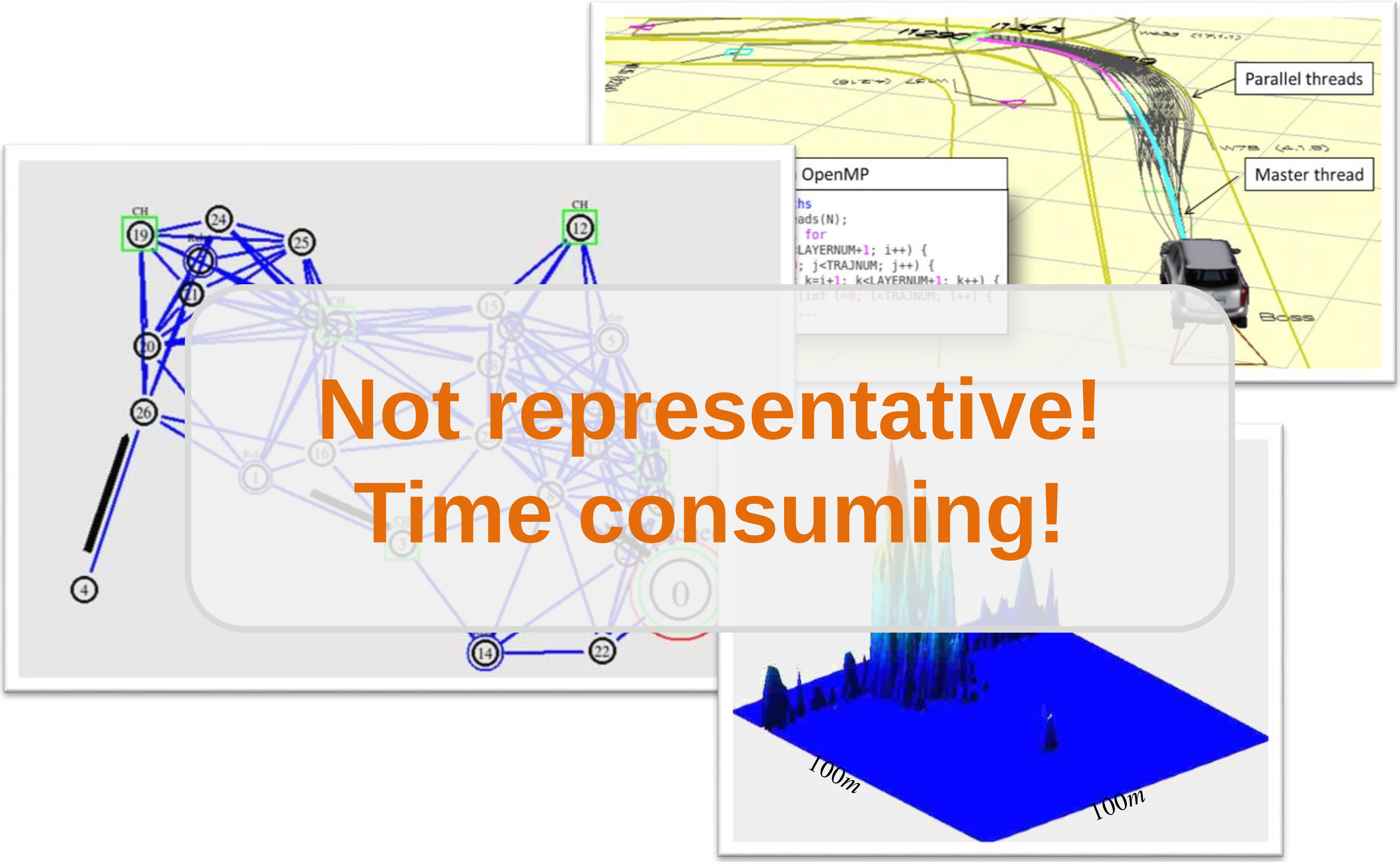
Does this look familiar?

Too complicated!

Not reproducible!

Dangerous!

Or is this more your cup of tea?



OpenMP

```
hs
ads(N);
 for
LAYERNUM+1; i++) {
; j<TRAJNUM; j++) {
 k=i+1; k<LAYERNUM+1; k++) {
(int l=0; l<TRAJNUM; l++) {
...
```

Not representative!

Time consuming!

Problem Statement

Opportunity:

Empirical evidence of the use and effectiveness of verification and validation strategies in CPS is largely anecdotal

Gap:

It is not clear what is truly demanded by modern CPS with respect to tools and techniques for verification and validation

Challenges: Real world scale, dynamics, safety, repeatability

This work starts with an **empirical study** of the state of the art and state of the practice of **verification and validation** of **cyber-physical systems**. It uses this study to motivate essential **research directions** for CPS V&V.

Strongly Held Belief 1

CPS developers are generally unfamiliar with traditional software verification and validation methodologies

- CPS developers are often **domain experts**, not software engineering experts
- Many often have a very different view of the software engineering process than we traditionally do

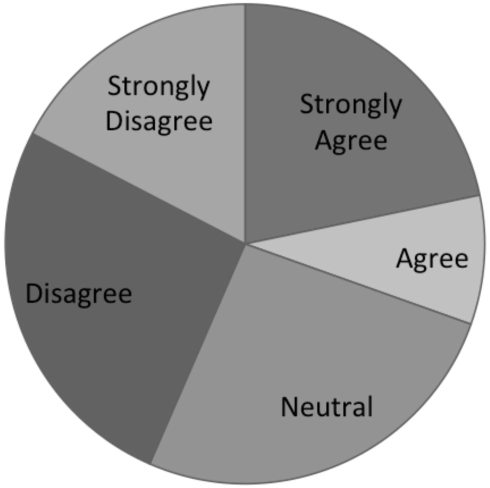
TRUE

Strongly Held Belief 2

High-level programming languages (e.g., Java) are not applicable to CPS

- Many CPS developers prefer low-level languages like nesC and other proprietary languages
- However, many also choose languages like Java, C++, Python, etc.

"A programming language like Java is not applicable to systems with hard real-time constraints"



Strongly Held Belief 3

Resource constraints (e.g., CPU, memory, and storage) are a major issue in developing and debugging CPS

- Low levels (e.g., sensor implementations) have to be concerned about resource constraints
- However, many of the tasks of CPS developers are constrained to the higher (application layers)
  - Developers assume lower levels have abstracted away resource constraint concerns

MYTH

Strongly Held Belief 4

Existing model checking and other formal techniques are insufficient to meet CPS applications' needs

- CPS developers believe that formal techniques:
  - Have learning curves that are too steep
  - Are computationally inefficient for large-scale systems

TRUE

- However, CPS developers commonly desire to use formal techniques, at least for components of the system

Strongly Held Belief 4 (More details)

There is a significant gap in between models of computing and communications and models of physics that makes applying them jointly in CPS challenging.

- CPS inherently intertwines cyber and physical
  - But tools and techniques for debugging the CPS generally focus on one or the other (often depending on the expertise of the user)
- **Teaser**: conceptually, models ought to be practically usable, e.g., for testing and debugging

Strongly Held Belief 5

An ad hoc, trial-and-error approach to development is the state of the art for CPS systems

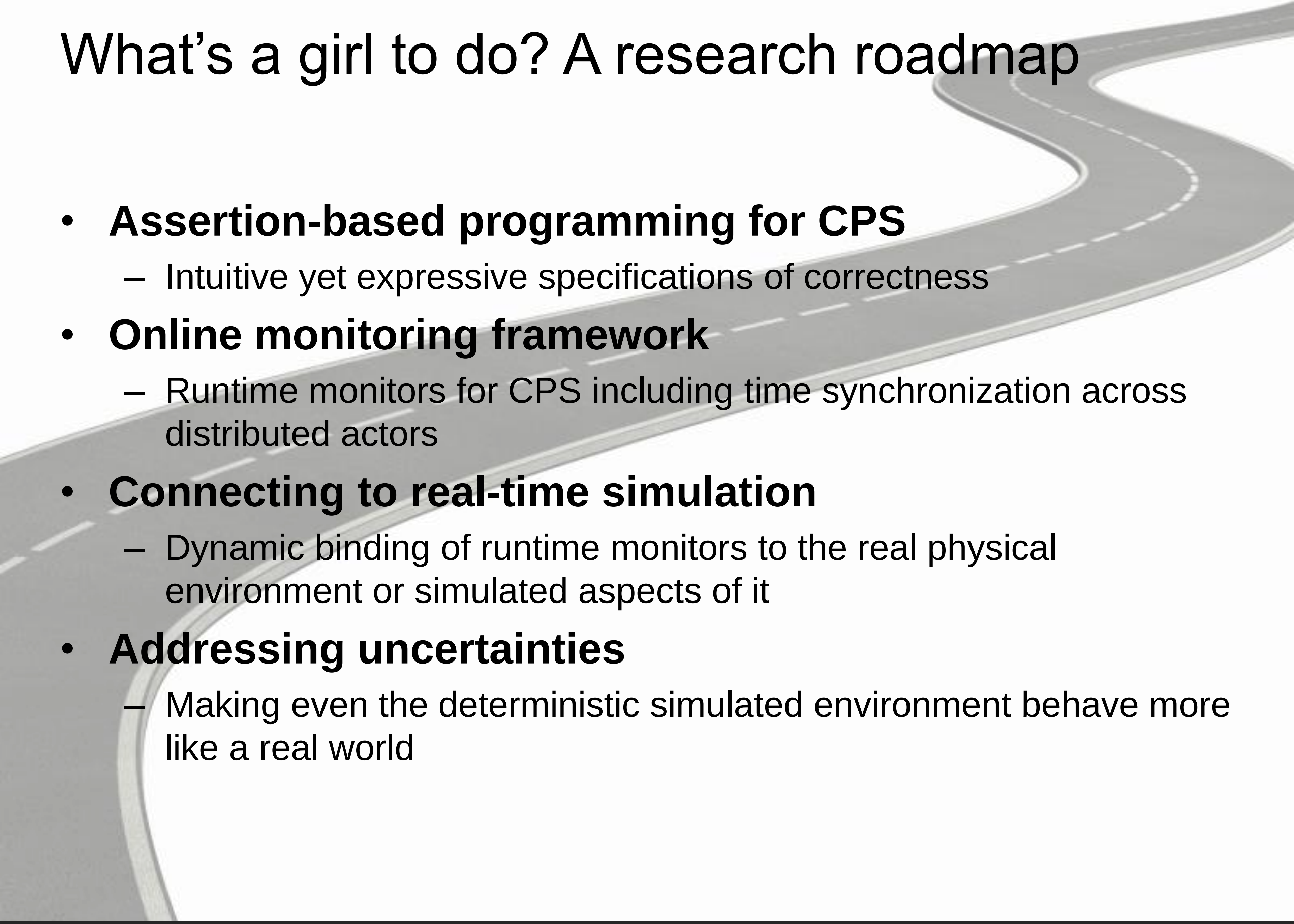
- 91.3% of the survey respondents either “Agree” or “Strongly Agree” with this statement

TRUE

Key Takeaways

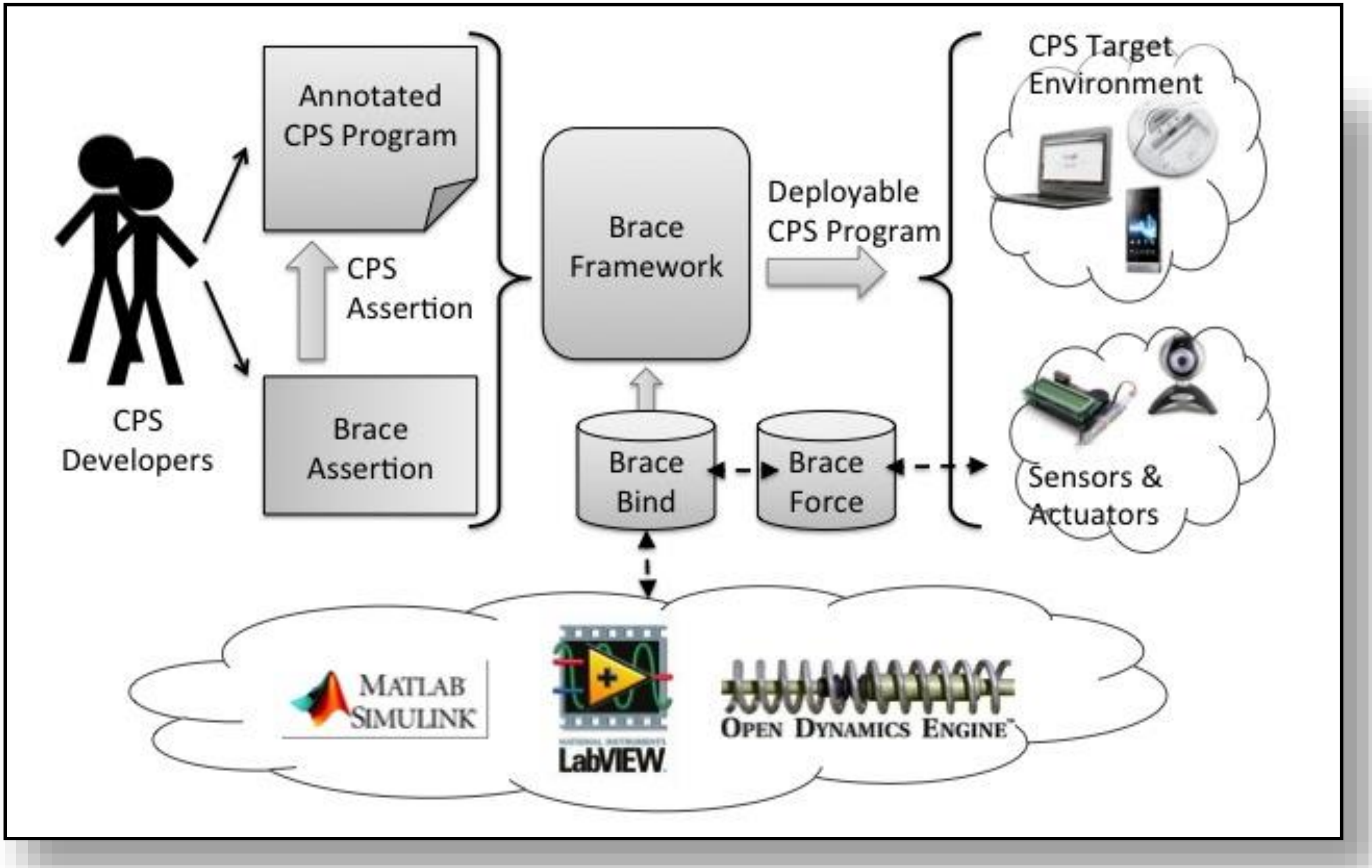
- Trial-and-error testing (which is the state of the practice) does not provide sufficient rigor in error detection
- Formal methods provide a desired level of expressiveness but are neither intuitive nor efficient
- Existing simulation tools are limited in their capabilities to jointly model physical and cyber components

What’s a girl to do? A research roadmap



- **Assertion-based programming for CPS**
  - Intuitive yet expressive specifications of correctness
- **Online monitoring framework**
  - Runtime monitors for CPS including time synchronization across distributed actors
- **Connecting to real-time simulation**
  - Dynamic binding of runtime monitors to the real physical environment or simulated aspects of it
- **Addressing uncertainties**
  - Making even the deterministic simulated environment behave more like a real world

The Brace Framework



Questions?

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