Research Challenges in CPS

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Quick History

Embedded Systems
1980: e.g. airbag
Quick History

> 40 processors, 60 sensors, 40 actuators
> 100 million lines of code controlling them

Networked Embedded Systems
1990: e.g. car

Embedded Systems
1980: e.g. airbag
Quick History

Cyber-Physical Systems
2010: e.g. smart mobility

Networked Embedded Systems
1990: e.g. car

Embedded Systems
1980: e.g. airbag
CPS Wake-Up Call

2008: NSF and US-Scientists send CPS-Manifesto to
  • The president of the US
  • President’s Council of Advisors on Science and Technology
  • NSF program takes off in February 2009 within the US

2012: Acatech and DE-Scientists send CPS-Manifesto to
  • Germany’s Federal Ministry of Education and Research
  • Program takes off in 2013 in Germany
  • H2020 program takes off in 2014 within the EU

It is high time for a Big-Push in Austria, too!
CPS Week 2016

HSCC  ICCPS  IPSN  RTAS

Vienna, Austria

April 12-14, 2016
(Workshop & Tutorials: April 11, 2016)

http://cpsweek2016.ocg.at
Where Are We Now?

Unmanned Trains

Unmanned Cars

Unmanned Aerial Vehicle

Unmanned Underwater Vehicle

Unmanned Factory

Cyber Biological
What are the Grand Challenges?

• Zero traffic-fatalities
• Blackout-free electricity
• Energy-aware buildings
• On-the-fly production
• Everywhere health-care
• Max-yield agriculture
The CPS Ecosystem

- Internet of Things (IoT)
- Industry 4.0
- CPS
- Smarter Planet
- Machine to Machine (M2M)
- The Swarm
- The Fog
- The Cloud
- Industrial Internet
What are the Technical Challenges?

**Mathematics**
- Discrete-continuous
- Very different math

**Architecture**
- Huge complexity
- CPS-OS platform

**Spacetime**
- Various scales of ST
- ST-aware programs
What are the Technical Challenges?

Uncertainty

- Partial knowledge
- Limited resources

Orbitals of the hydrogen atom
while \((x > x_0)\) go back;
while \((\theta > \theta_0)\) turn;
...

Not smart/robust
- Optimization tough
- Not robust (sliding)

Optimization goal: Learn \(x_0, \theta_0, \ldots\)
Capturing freedom
Capturing freedom: Neural Network

N(x_0, \sigma_1) \rightarrow O: \rightarrow N(\theta_0, \sigma_2)

\begin{align*}
\mu &= 0, \quad \sigma^2 = 0.2, \\
\mu &= 0, \quad \sigma^2 = 1.0, \\
\mu &= 0, \quad \sigma^2 = 5.0, \\
\mu &= -2, \quad \sigma^2 = 0.5,
\end{align*}

\begin{align*}
\Phi_{\mu,\sigma^2}(x) &= \frac{1}{\sqrt{2\pi\sigma^2}} \exp\left(-\frac{(x-\mu)^2}{2\sigma^2}\right),
\end{align*}
Stochastic Algorithm

- **Ontology O**: Neural Network of guard dependencies

\[
\text{ntwhile } (x > x_0, \sigma_0) \text{ go back}; \quad \theta_1 = O_\theta(x)
\]
\[
\text{ntwhile } (\theta > \theta_1, \sigma_1) \text{ turn}; \quad \sigma_1 = O_\sigma(x)
\]

\[
x_0, \sigma_1
\]
Determinization Trick (e.g. In Time): Use lol
Classification (Prediction) Limits in FOT

What about: First Order Theory \((\mathbb{R}, \leq, +, \times, \sin)\) ?

– Undecidable: Would allow encoding of polynomial diophantine equations (PDE)
– PDE: Known to be undecidable (Matiyasevich, 1970)
Fixing Precision (i.e. Use lol)

What about: FOT ($\mathbb{R}, \leq, +, \times, \sin$) ?

Decidable: But exponential in the number of boxes!
Top-Down Algorithm

What about: FOT ($\mathbb{R}, \leq, +, \times, \sin$)?
Top-Down Algorithm

What about: $\text{FOT} \ (\mathbb{R}, \leq, +, \times, \sin)$?
Top-Down Algorithm

What about: FOT \((\mathbb{R}, \leq, +, \times, \sin)\)?
Top-Down Algorithm

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Top-Down Algorithm

What about: FOT (\( \mathbb{R}, \leq, +, \times, \sin \))?
Top-Down Algorithm

By fixing precision: Always terminates!

- **Consequence**: Uncertainty within white boxes (lol)
- **Time Domain**: Time triggered approach
- **Value Domain**: Similar to time domain abstraction
What are the Technical Challenges?

Uncertainty
• Partial knowledge
• Limited resources

Safety
• Safety is in big no
• Emergent behavior

Smartness
• Adapting is in big no
• Neural circuits
What About Education?

Recent past (1980-2010s)
- Blind man assessing an elephant
- Blind man building an elephant!

What about now?
- Age of system building!
- Engineering converges

Back in the future (1950s)
- Computation: von Neumann
- Sensing/inference: Wiener
- Actuation/Control: Kalman
- Communication: Shannon
What is in Store for Us?

Higher Productivity

Better Health

Clean Environment

Time for Family

Time for Ourselves

Time for Elderly

More Vacation

More Flexibility

More Learning