Cyber-Physical Systems Research Charge

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Cyber-Physical Systems Summit
St. Louis, MO
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Smart Cars

A BMW is “now actually a network of computers”
[R. Achatz, Siemens, Economist Oct 11, 2007]

Lampson’s Grand Challenge:
Reduce highway traffic deaths to zero.
[Butler Lampson, Getting Computers to Understand, Microsoft, J. ACM 50, 1 (Jan. 2003), pp 70-72.]

Cars drive themselves

Dash Express: Cars are nodes in a network

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Embedded Medical Devices

Pacemaker, dual-chamber

infusion pump

pacemaker

scanner
Sensors Everywhere

Sonoma Redwood Forest

Hudson River Valley

smart bridges

smart buildings

Credit: Arthur Sanderson at RPI

Kindly donated by Stewart Johnston

Credit: MO Dept. of Transportation

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Robots Everywhere

At work: Two ASIMOs working together in coordination to deliver refreshments

Credit: Honda

At home: Paro, therapeutic robotic seal

Credit: Paro Robots U.S., Inc.

At home/clinics: Nursebot, robotic assistance for the elderly

Credit: Carnegie Mellon University

At home: iRobot Roomba vacuums your house

Credit: iRobot

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CSTB National Academies Study

Software for Dependable Systems: Sufficient Evidence?
Daniel Jackson, Martyn Thomas, and Lynette I. Millett, Editors
May 9, 2007
#1 Priority: Cyber-Physical Systems
Our lives depend on them.
This is Not Science Fiction
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soldier in smart tank

battlefield with hidden mines

soldier on smart stretcher with smart dogtag

medicbot

IPv6

emergency supplies station

GIG

medic in MASH unit

IPV6

doctor making rounds

patient records

HMO

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State of the Art

• Point solutions for some of the aspects of the bigger problem
  - E.g., fault-tolerance, network security, NurseBot
  - E.g., verification of one safety property for one medical device

• What’s missing
  - Technical solutions for aspects of the bigger problem only partially addressed (e.g., secure wireless communication) or not addressed at all (e.g., reasoning about privacy)
  - Comprehensive solutions for whole problem, but perhaps for a specific application
Research Challenges
(Your Ideas Go Here)
Drivers of Computing

Science  

Society  

Technology
Societal Challenge

- How can we provide people and society with cyber-physical systems they can bet their lives on?

  - **Expectations**: 24/7 availability, 100% reliability, 100% connectivity, instantaneous response, store anything and everything forever, ...

  - **Classes**: young to old, able and disabled, rich and poor, literate and illiterate, ...

  - **Numbers**: individual → cliques → acquaintances → social networks → cultures → populations

*Cyber-Physical Systems will be everywhere, used by everyone, for everything*
Technical Challenge

• (How) can we build systems that interface between the cyber world and the physical world? Ideally, with predictable, or at least adaptable behavior.

• Why this is hard:
  - We cannot easily draw the boundaries.
  - Boundaries are always changing.
  - There are limits to digitizing the continuous world by abstractions.
  - Complex systems are unpredictable.
Fundamental **Scientific Challenges**

- Co-existence of Booleans and Reals
  - Discrete systems in a continuous world
- Reasoning about uncertainty
  - Human, Mother Nature, the Adversary
- Understanding complex systems
  - Emergent behavior, tipping points, ...
  - Chaos theory, randomness, ...
Communities Needed to Meet These Challenges
Disciplines and Sectors

• Academic Disciplines
  - Civil engineering
  - Control systems
  - Electrical engineering
  - Embedded systems
  - Formal methods
  - Human-computer interaction
  - Hybrid systems
  - Mathematics
  - Mechanical engineering
  - Networking
  - Operations research
  - Probability and statistics
  - Real-time systems
  - Robotics
  - Security and privacy
  - Software engineering
  - Systems engineering
  - Usability
  - ...

• Industrial Sectors
  - Aeronautics
  - Automotive
  - Buildings
  - Consumer/Home
  - Energy
  - Finance
  - Medical
  - Telecommunications
  - ...

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Broader Implications

• Nature of research
  - Interdisciplinary
  - Collaborative across disciplines, between industry and academia

• Education: Workforce and training
  - Discrete and continuous mathematics
  - Software, hardware, device and systems engineering
  - Need major improvements in Science, Technology, Engineering and Mathematics (STEM) education in K-12
Partnerships

- Theoreticians, experimentalists, domain experts
- Computer scientists, engineers (of all types)
- Industry, Academia, Government
  - domain experts, domain problems
  - general solutions that work for specific problems
A Model for Expediting Progress

- Industry
- Gov’t (e.g., military)
- Industry
- Gov’t
- Academia
- Academia
- Gov’t (NSF, NSA, NIH, DoD, …)

Sectors
- medical
- aero
- finance
- transportation
- civil
- energy
- chemical
- materials

Fundamental Research
New Models for Academia-Industry-Government Partnership

• For example: Google+IBM and NSF
  - Google+IBM providing software and services on large data cluster to academic community reached by NSF. Why?
    • NSF’s broad reach: all US academic institutions, all sciences and engineering
    • NSF’s merit review process and infrastructure

• Other companies welcome!
• Other models of engagement welcome!
Where are We Now:

NITRD
NSF
US

- Air Force Research Laboratories*
- Army Research Office and Space and Defense Systems*
- Department of Defense/ OSD
- Defense Advanced Research Projects Agency
- Department of Energy
- Federal Aviation Administration*
- Food and Drug Administration*
- National Air & Space Administration
- National Institutes of Health
- National Institute of Science and Technology
- National Science Foundation
- National Security Agency
- Office of Naval Research*

* Cooperating agencies
NITRD/HCSS Activities towards R&D Needs Assessment

**Real-time technology assessment:**
Industry Non-Disclosure Briefings

**Domain-specific workshops**
- Medical Devices and Systems
- Aviation Systems and Certification
- Beyond SCADA and DCS
- Future Automotive Systems

**National Academies Study**
Software for Dependable Systems: Sufficient Evidence?

**Verification Grand Challenge**

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**“HC – RTOS” Workshop Planning Meeting**

**National Workshop on New Research Directions in High Confidence Software Platforms for Cyber Physical Systems**
(Nov 30 – Dec 1, 2006)

**Workshop on Composable Systems Technologies for Cyber Physical Systems**
(July 9-10, 2007)
Research Needs Assessment - Resources

- **High Confidence Medical Device Software and Systems (HCMDS)**

  - Planning Workshop, Seattle, WA, November 9-10, 2005, [http://chess.eecs.berkeley.edu/hcssas/previousMeetings.html](http://chess.eecs.berkeley.edu/hcssas/previousMeetings.html)

- **High Confidence Critical Infrastructures: “Beyond SCADA: Networked Embedded Control Systems” (NSF, NIST, NSA)**

- **High Confidence Automotive Cyber-Physical Systems**
  - Planning meeting: RTSS, Tucson, December 3, 2007
Research Needs Assessment, cont’d.


  - Kickoff workshop, April 2004, “Software Certification and Dependability” (report)
  - Report released, October 23, 2007

• CPS Workshop, Austin, TX October 16-17, 2006, draft report, http://ike.ece.cmu.edu/twiki/bin/view/CpsReports/WebHome


• Open Verification Initiative
Upcoming HCSS Actions

• Planned Workshops
  - Future (green) energy systems workshop
    • Date TBD, late summer early autumn?
    • NSF ENG and CISE directorates, HCSS
  - Net Zero Energy Buildings workshop (joint? co-located?)
  - Joint aviation/automotive CPS follow-on workshop?

• May 20, 2008 GSA/HCSS Expedition (at NSF): “Potentials and Realities of Certification in Light of Open Technology Development ...”
To explore the conducive conditions for certification within and across multiple critical cyberinfrastructures that share a common need for high confidence software and systems that advance national preparedness, public safety, and economic growth. How are technical advances, sources of supply, and interdependencies measuring up or falling short of national demands for high confidence in critical technologies and cyberinfrastructures? Have certification programs to mitigate risk kept pace with technology advances? If not, what needs to be done? Given the continuum of open systems architecture, what does the landscape for dependable software approaches look like today?
Where Are We Now? NSF View

2005-2007
NITRD/HCSS Interagency Workshops, reports
Coming soon: HCSS-CPS?

NSF Real-Time GENI Workshop, Oct. 2006

NSF Cyber-Physical Systems Workshop
(Oct 16-17, 2006)

Industry Roundtable
May 17, 2007

PCAST Report: NIT for Resilient Physical Systems
August, 2007

National Academies Study
Software for Dependable Systems: Sufficient Evidence? (released)

Verification Grand Challenge 2006-7
-> VSTTE IFIP Working Conference
-> Evidential Tool Bus
-> Open Verification Platform

FY 2007: CPS seedling
FY 2008: CPS-T & CPS-E
CPS TODAY:
FY 2009 and Beyond?
EU-US Collaboration in Embedded Systems

• **Cooperative Actions, US Component**
  - FY 2004 - ITR supplement program initiated
  - FY 2005 - supplement program continued; ITR ended

• **Working Meetings:**
  - 2000-2002 - Helsinki, Grenoble, Duesseldorf, Lansdowne, VA, September
  - 2005 - Zurich (HSCC), Paris, Ljubljana
  - 2006 - Washington, DC, Helsinki
  - 2007 - Brussels FP7 Information Day, Cambridge Workshop, Arlington HCSS Composable System Technologies
  - 2008 - CPSWeek St. Louis, TBD: Stockholm
CPS At NSF


- CPS Funding Opportunities
  - FY 2007, exploratory CSR theme, NSF 07-504
    - CPS-T - technology base for cyber-physical systems
    - CPS-E - exploratory, experimental research
  - FY 2009 - *Under Construction*, expected summer 2008
    - CISE (all divisions) + ENG directorates working together

CISE CPS Academic Summit, St. Louis, April 25, 2008
Summary and Next Steps

• Please read Executive Summary off of CPS Summit webpage

• http://varma.ece.cmu.edu/summit/index.html
Charge To You

I. Define a compelling research agenda on cyber-physical systems

- What visions can we state for the medium/long-term future?
  - Grand Challenge Problems
    - e.g., Butler Lampson's Reduce highway traffic deaths to zero [J. ACM 50, 1 (Jan. 2003), pp 70-72.]
    - Scenarios: “Imagine a world where ...”

- What are the fundamental research questions?
- What are the key social, technical, and scientific drivers for CPS research?
  - Baseline: Where are we now?
  - Projection: What do we need to get to where we want to be?

- What are examples of promising solutions?
  - Plausibility of research agenda

Purpose: Identify the scope, both breadth and depth, of research agenda.
Charge to You

II. Propose a plan of action to carry out the research agenda

- What new modes of engagement will make a dramatic difference?
  - Breaking down barriers between disciplines, between academia and industry, between generalists and domain experts

- What disciplines need to be involved?
- What is the role of industry?
- What is the role of NSF and other gov’t agencies?
Charge to You

III. How can CISE and more broadly NSF and other agencies help?

- What other directorates should be involved? What other agencies?
- What is a sensible range of single PI to center-sized awards?
Not Business as Usual

1. **Usual:** Your report should make a compelling case for a CPS research agenda.

   *NBaU:* NSF can use this report to shape a new broad-based initiative.
Not Business as Usual

2. Usual: What is the next hard problem in my community to work on?

_{NBaU:} Think out of the box. Have courage to work out of your comfort zone. Think transformative.

_{NBaU:} If my community has something to add to advance progress in CPS, what would it be?

_{NBaU:} Think problem-driven.
Not Business as Usual

3. Usual: Think rather than “Here’s an opportunity for my community” …

NBaU: …instead think that

We are building a new CPS community.

We need your expertise, your research sensibilities. This is an opportunity for YOU and we need YOU!
Thank You

• Your ideas will help shape the CPS research agenda.

• Your time, energy, and effort spent are a great service to the community.
Thanks

- **Organizing Committee:** Bruce Krogh, Edward Lee, Insup Lee, Al Mok, George Pappas, Raj Rajkumar, Harvey Rubin, Alberto Sangiovanni-Vincentilli, Lui Sha, Kang Shin, Jack Stankovic, Janos Sztipanovits, Wayne Wolf, Wei Zhao

- **CCC:** Sue Graham, David Waltz

- **NSF Team:** Helen Gill, Scott Midcliff, Ty Znati, Michael Branicky (coming)
Thank you!
Credits

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