Cyber-Physical Systems

S5: Safe & Secure Software & Systems Symposium
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Overview

- What are Cyber-Physical Systems?
- CPS Scientific Challenges
- CPS: An Interagency Agenda
- Pilot at the NSF: NSF FY09, FY10 CPS Competitions
- Next Gen CPS Workforce: “CPS Capable”
- The CPS Virtual Organization: Building CPS Community
- Conclusion
National Priorities and Challenges

- **Healthcare**

- **Energy**

- **Environment**

- **Economy: Sectors**
  - Manufacturing capacity, efficiency, agility
  - Energy and environmental technologies
  - Transportation: aviation, automotive, rail
    - Costs: Toyota, DC Metro, Airbus …
  - Biomedical and health technology
Is There a Problem to Be Solved?

- Example: automotive industry challenges, recalls
- Example: FDA Infusion Pump Initiative
- Example: Gulf of Mexico, other environmental disasters
- Loss of capacity for innovation
  - Shuttered factories
  - Decline in workforce capability, loss of skilled workforce
  - Education challenges
- Need for increased capability, resulting growth of system complexity
What are Cyber-Physical Systems?
What are Cyber-Physical Systems?

- **Cyber** – computation, communication, and control that are discrete, logical, and switched

- **Physical** – natural and human-made systems governed by the laws of physics and operating in continuous time

- **Cyber-Physical Systems** – systems in which the cyber and physical systems are tightly integrated at all scales and levels
  - Change from cyber merely appliqué’d on physical
  - Change from physical with COTS “computing as parts” mindset
  - Change from ad hoc to grounded, assured development

“CPS will transform how we interact with the physical world just like the Internet transformed how we interact with one another.”
Some hallmark characteristics:

- Cyber capability in every physical component
- Networked at multiple and extreme scales
- Complex at multiple temporal and spatial scales
- Constituent elements are coupled logically and physically
- Dynamically reorganizing/reconfiguring; “open systems”
- High degrees of automation, control loops closed at many scales
- Unconventional computational & physical substrates (such as bio, nano, chem, …)

**Operation must be dependable, certified in some cases**
A BMW is “now actually a network of computers”

Lampson’s Grand Challenge:
*Reduce traffic deaths to zero*
Similar Problems in Many Sectors

- **Energy**: smart appliances, buildings, power grid
  - Net-zero energy buildings
  - Minimize peak system usage
  - No cascading failures

- **Healthcare**: embedded medical devices and smart prosthetics; operating room of the future; integrated health care delivery
  - Patient records available at every point of care
  - 24/7 monitoring and treatment

Kindly donated by Stewart Johnston
Model for Expediting Progress*

- A new underlying discipline
- Abstracting from sectors to more general principles
- Apply these to problems in new sectors
- Build a new CPS community

* Jeannette M. Wing
  Assistant Director, CISE, NSF
New Horizons
CPS Scientific Challenges
CPS Research Gaps

Research Gaps
- Composition
- Design automation
- System integration
- Certification
- Security and privacy
- Education and work force

Cyber
- Discrete
- Synchronous Procedures
- Sequences
- Computing Abstractions
- Computer Science

Physical
- Continuous
- Asynchronous Events
- Time
- Laws of Physics
- Domain Engineering
CPS Challenges

- Societal challenge – CPS people can bet their lives on

- Technical challenge – Systems that interface the cyber and physical, with predictable behavior

  - Where are the boundaries?
  - What are the limits to abstracting the physical world?
  - Are complex CPS too unpredictable?
  - Can we transcend overly conservative design?
S5 and CPS: Not Just Business as Usual

- Not simply robotics/motion control/vision – rather, design for certifiably dependable control of (complex) systems

- Principles for bridging control, real-time systems, safety, security (not just a platform question – rather an interdisciplinary systems science issue)

- Next generation system architectures, a recurring question: “What’s in a mode?” (cooperation/coordination? is the safety controller reachable?)

- Next generation system ID (bridging machine learning with traditional system ID state estimation, stochastics and uncertainty, purpose: reactive and predictive control)

- Next generation fault tolerance (not just TMR: multicore/many-core, new forms of analytic and synthetic redundancy for FT, addressing interference and interaction, including separation/correlation reasoning)

- Next generation real-time systems (coordinated, dynamic multisystem scheduling; property-preserving scheduling; timed networks, precision timing)

- FPGAs and other reconfigurables; not just “software” – rather, next generation DA and PLs, system abstractions, software/system co-synthesis

- Safe AND Secure, Resilient AND Capable
CPS: An Interagency Agenda
Eight priority areas for competitiveness, with four designated as having the highest priority

- Network and Information Technology (NIT) Systems Connected with the Physical World
- Software
- Digital Data
- Networking

NIT systems connected with the physical world (cyber-physical systems)

- Essential to the effective operation of U.S. defense and intelligence systems and critical infrastructures
- At the core of human-scale structures and large-scale civilian applications
NI TRD/ HCSS Interagency 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
- Future Transportation Systems
- Future Energy Systems

National Academies Study
Software for Dependable Systems: Sufficient Evidence?

Verification Grand Challenge

“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)
Selected Workshops on CPS

- High-Confidence Medical Device Software and Systems Workshop, June 2005, Phila., PA
- Beyond SCADA: Networked Embedded Control for Cyber Physical Systems, Nov. 2006, Pittsburgh, PA
- High-Confidence Software Platforms for Cyber-Physical Systems, Nov. 2006, Alexandria, VA
- Joint Workshop On High-Confidence Medical Devices, Software, and Systems and Medical Device Plug-and-Play Interoperability, June 2007, Boston, MA
- Composable and Systems Technologies for High-Confidence Cyber-Physical Systems, 2007, Arlington, VA
- High-Confidence Automotive Cyber-Physical Systems, April 2008, Troy, MI
- CPS Summit, CPS Week, April 2008, St. Louis, MO
- Robotics and Cyber-Physical Systems Special Session at IROS, Sept. 2008, Nice, FRANCE
- Transportation Cyber-Physical Systems: Automotive, Aviation, and Rail, November 2008, Vienna, VA
- Future Cyber-Physical Energy Systems Workshop, June 2009, Baltimore, MD

CPS Summit Website: http://varma.ece.cmu.edu/summit/Workshops.html
Each Workshop: Expected Outcome

- Report series on networking and information technology research needs, edited and published by the National Coordination Office (NCO) for Networking and IT R&D (NITRD)
  - High Confidence Medical Devices, Software, and Systems (published, 2008)
  - Future Transportation CPS (editing underway)
  - Future Energy CPS (most recent workshop)
  - ...

- Each report contains:
  - Community-based research needs assessment, product of one or more workshops
  - Government analysis of research needs for the area

- Interagency CPS Initiative workshop, March 2010

- PCAST update underway
Pilot at the NSF

(“If you build it, will they come?”)

NSF FY09, FY10 CPS Competitions
CPS Solicitation (NSF 08-611)

- Joint initiative of Directorate for Computer and Information Science and Engineering (CISE) and Directorate for Engineering (ENG)
- Proposals were due February 27, 2009
- Total expected funding of up to about $30M, 30-40 awards
- Continuation in future years is expected

http://www.nsf.gov/funding/pgm_summ.jsp?pims_id=503286

- FAQ
- Information Day and Community Workshop
Type of CPS Projects

- **Small Projects** – individual or small-team efforts that focus on one or more of the three defined CPS themes (up to $200,000/year for up to three years)

- **Medium Projects** – span one or more CPS themes and may include one or more PIs and a research team of students and/or post-docs (up to $500,000/year for up to three years)

- **Large Projects** – multi-investigator projects addressing a coherent set of research issues that cut across multiple themes or that explore a particular theme in great depth (up to $1,000,000/year for up to five years)

- **Virtual Organization** – facilitate and foster collaboration and information exchange (R2R, R2I)
Three CPS Themes

- **Foundations** – develop new scientific and engineering principles, algorithms, models, and theories for the analysis and design of cyber-physical systems

- **Research on Methods and Tools** – bridge the gaps between approaches to the cyber and physical elements of systems through innovations such as novel support for multiple views, new programming languages, and algorithms for reasoning about and formally verifying properties of complex integrations of cyber and physical resources

- **Components, Run-time Substrates, and Systems** – new hardware and software infrastructure and platforms and engineered systems motivated by grand challenge applications
Peer Review: “Not Business as Usual”

- Innovative research that spans the boundaries of engineering and computer science and subdisciplines

- Balance and integrate both cyber and physical aspects

- Not
  - cyber merely appliquéd on physical
  - physical with COTS “computing as parts” mindset
  - recycled from a focused disciplinary research program
  - anecdotal case studies (rather -- general CPS principles)
Program management

Not merely a “grants” program

- NSF 08-611 (and NSF10-515): PIs expected to participate in PI meetings
- CPS Virtual Organization will enable coordination across projects and with industry, community-building
- Future: possible incentives (e.g., supplements) to enable research teaming that spans projects, links to other entities
- NSF CPS PD team will actively monitor and assess both individual projects and overall program progress

Goal: sustained interactions outside of NSF

- NITRD and US mission agencies
- Industry
- Research communities
  - IEEE, ACM
  - CPS Week, ESWEEK, CDC, ACC, ICRA, CAV …
  - CRA and the Computing Community Consortium (CCC)
- International research cooperation
Predictions and Speculations

LZ: ~100 proposals
HG: ~200 proposals
MB, BK, TZ: 250-300 max
Overwhelming Response

642 Proposals !?!
FY09 CPS Competition and Portfolio
NSF Baseline - CI SE-ENG CPS Program
FY09: By the Numbers

- 642 Proposals, totaling $580M in requests
- 527 CPS Projects, $45M in awards ($15.8M ARRA)
  - 248 Small
  - 249 Medium
  - 29 Large
  - 30 funded (~12%)
  - 26 funded (~10%)
  - 2 funded (~7%)

- CPS Virtual Organization Award: Vanderbilt University
  - CPS community-building and support: project portals, wikis, etc.
  - Support for experimental platforms, research results
  - PI meeting support, industry and interagency engagement
First Year (FY 2009) Awards

- Health and medicine
- Energy and environment
- Transportation (aviation and automotive)
- New system science
- Platforms
New Systems Science

- CPS:Large: ActionWebs
  Claire Tomlin, et al (UC Berkeley)
  http://www.nsf.gov/awardsearch/showAward.do?AwardNumber=0931843

- CPS:Small: Control Design for CyberPhysical Systems Using Slow Computing
  Richard M Murray (CalTech)
  http://www.nsf.gov/awardsearch/showAward.do?AwardNumber=0931746

- CPS: Small: Compositionality and Reconfiguration for Distributed Hybrid Systems
  Andre Platzer, Edmund M Clarke (CMU)
  http://www.nsf.gov/awardsearch/showAward.do?AwardNumber=0931985

- CPS: Small: Collaborative Research: Establishing Integrity in Dynamic Networks of Cyber Physical Devices
  Vinod Ganapathy and Ulrich Kremer (Rutgers U), Trent Jaeger (Penn State U)
  http://www.nsf.gov/awardsearch/showAward.do?AwardNumber=0931992

- CPS: Small: Collaborative Research: Localization and System Services for SpatioTemporal Actions in Cyber-Physical Systems
  Rajesh Gupta (UCSD), Anish Arora (Ohio State U), Jay Bayne (Meta Command Systems, Inc.)
  http://www.nsf.gov/awardsearch/showAward.do?AwardNumber=0932360
CPS:Large: ActionWebs
Claire Tomlin, et al (UC Berkeley)
http://www.nsf.gov/awardsearch/showAward.do?AwardNumber=0931843

CPS: Medium: Collaborative Research: Abstraction of Cyber-Physical Interplays and Its Application to CPS Design
Kang Shin and Ella Atkins (U. Mich), C. Mani Krishna and Israel Koren (U Massachusetts, Amherst)
http://www.nsf.gov/awardsearch/showAward.do?AwardNumber=0930813

CPS: Medium: High Confidence Active Safety Control in Automotive Cyber-Physical Systems
Francesco Borrelli, Ruzena Bajcsy, Karl Hedrick (UC Berkeley)
http://www.nsf.gov/awardsearch/showAward.do?AwardNumber=0931437

CPS: Medium: Vehicular Cyber-Physical Systems
Hari Balakrishnan, Samuel Madden, Daniela Rus (MIT)
http://www.nsf.gov/awardsearch/showAward.do?AwardNumber=0931550

CPS: Medium: Autonomous Driving in Mixed-Traffic Urban Environments
Umit A Ozguner, Umit A Ozguner, Ashok K Krishnamurthy, Fusun Ozguner, Paolo A Sivilotti, Bruce W Weide (Ohio State U)
http://www.nsf.gov/awardsearch/showAward.do?AwardNumber=0931669

CPS: Medium: Tightly Integrated Perception and Planning in Intelligent Robotics
Mark E Campbell, Daniel P Huttenlocher, Hadas Kress Gazit (Cornell)
http://www.nsf.gov/awardsearch/showAward.do?AwardNumber=0931686
Health and Medicine

CPS:Medium: Hybrid Systems for Modeling and Teaching the Language of Surgery
Gregory D Hager, Sanjeev P Khudanpur, Rajesh Kumar, Rene Vidal (JHU)
http://www.nsf.gov/awardsearch/showAward.do?AwardNumber=0931805

CPS:Medium: Image Guided Robot-Assisted Medical Interventions
Nikolaos Tsekos, Zhigang Deng, Karolos M Grigoriadis, Ioannis A Kakadiaris, Javad Mohammadpour (U of Houston)
http://www.nsf.gov/awardsearch/showAward.do?AwardNumber=0932272

CPS Small: Control of Surgical Robots: Network Layer to Tissue Contact
Blake Hannaford, Howard J Chizeck (U Washington)
http://www.nsf.gov/awardsearch/showAward.do?AwardNumber=0930930

CPS:Medium: Collaborative Research: Infrastructure and Technology Innovations for Medical Device Coordination
John Hatcliff, Dan Andresen, Robby, Steve Warren (KSU), Insup Lee, Oleg Sokolsky (U Pennsylvania)
http://www.nsf.gov/awardsearch/showAward.do?AwardNumber=0932289

Cybernetic interfaces for the restoration of human movement through functional electrical stimulation
Eric Perreault (RIC, Northwestern), et al
http://www.nsf.gov/awardsearch/showAward.do?AwardNumber=0932263

CPS:Medium: Programmable Second Skin to Re-educate Injured Nervous Systems
Eugene C. Goldfield (Harvard Medical School, Children’s Hospital Corp), Rob Wood and Radhika Nappal (Harvard University), Dava Newman (MIT), Marc Weinberg (Draper), Kenneth Holt and Elliot Saltzman (BU)
http://www.nsf.gov/awardsearch/showAward.do?AwardNumber=0932015

CPS: Small: Cyber-physical system challenges in man-machine interfaces: context-dependent control of smart artificial hands through enhanced touch perception and mechatronic reflexes
Veronica J Santos, Stephen I Helms Tillery (Arizona State U)
http://www.nsf.gov/awardsearch/showAward.do?AwardNumber=0932389
CPS: Medium: Collaborative Research: Monitoring Human Performance with Wearable Accelerometers
Jessica Hodgins, Fernando de la Torre (CMU), Mark Redfern (U of Pittsburgh)
http://www.nsf.gov/awardsearch/showAward.do?AwardNumber=0931999

CPS: Medium: Active Heterogeneous Sensing for Fall Detection and Fall Risk Assessment
Marjorie Skubic, Zhihai He, Dominic K Ho, James M Keller, Mihail Popescu (U Missouri)
http://www.nsf.gov/awardsearch/showAward.do?AwardNumber=0931607

CPS: Small: Collaborative Research: Foundations of Cyber-Physical Networks
Jiawei Han (UIUC), John Stankovic (U Virginia)
http://www.nsf.gov/awardsearch/showAward.do?AwardNumber=0931975
CPS: Medium: LoCal - A Network Architecture for Localized Electrical Energy Reduction, Generation and Sharing
Randy Katz, Eric A Brewer, David E Culler, Seth R Sanders (UC Berkeley)
http://www.nsf.gov/awardsearch/showAward.do?AwardNumber=0932209

Rohit Negi, Franz Franchetti, Marija D Ilic, Ole Mengshoel (CMU)
http://www.nsf.gov/awardsearch/showAward.do?AwardNumber=0931978

CPS: Medium: Collaborative Research: GOALI: Methods for Network-Enabled Embedded Monitoring and Control for High-Performance Buildings
Prabir Barooah (U. Florida), Alberto Speranzon (UTRC), Prashant Mehta and Sean Meyn (UIUC), Luca Carloni (Columbia)
http://www.nsf.gov/awardsearch/showAward.do?AwardNumber=0931885

GOALI/CPS: Medium: A Framework for Enabling Energy-Aware Smart Facilities
Lucio Soibelman, H. Scott Matthews, Jose Moura (CMU), Burton Andrews and Diego Benitez (Bosch)
http://www.nsf.gov/awardsearch/showAward.do?AwardNumber=0930868

CPS: Medium: Cyber-Enabled Efficient Energy Management of Structures (CEEMS)
Tyrone Vincent, Robert Braun, Dinesh Mehta, Kevin Moore, Siddharth Suryanarayanan (Colorado School of Mines)
http://www.nsf.gov/awardsearch/showAward.do?AwardNumber=0931748
CPS: Small: Community-based Sense & Respond -- Theory and Applications
Andreas Krause, K. Mani Chandy, Robert W Clayton, Thomas H Heaton (CalTech)
http://www.nsf.gov/awardsearch/showAward.do?AwardNumber=0932392

CPS: Medium: Collaborative Research: Physical Modeling and Software Synthesis for Self-Reconfigurable Sensors in River Environments
Jonathan Sprinkle (U. Arizona), Sonia Martinez (UCSD), Alex Bayen (UC Berkeley)
http://www.nsf.gov/awardsearch/showAward.do?AwardNumber=0930919

Michael D Lemmon, Xiaobo Hu (Notre Dame U)
http://www.nsf.gov/awardsearch/showAward.do?AwardNumber=0931195
FY 2010 Solicitation:

- Small changes for FY 2010
  - 2009 VO award in place, no subsequent VO competition
  - Minor clarifications
  - Proposal deadline: March 11, 2010

- Total planned funding of up to about $30-34M, 30-40 awards
- No stimulus funds expected for FY 2010
Next Gen CPS Workforce
“CPS Capable”
Capable Workforce for Future Physical and Engineered Systems

- Power generation and distribution
  - Deregulation, competition
  - Mix of generation technologies
    - Fossil fuels
    - Solar, wind
    - Hydrogen, fuel cells
    - Fusion?
- Future airspace
  - Airspace management
    - Free flight
    - UAVs
    - Critical Infrastructure
  - Higher performance vehicles
- Health care
  - Infusion pumps, ventilators,…
  - EMT and ICU of the future
  - Triage and transport
  - Home care
- General transportation
  - Highway system technologies
  - Vehicle technologies
    - Hybrid engines, alternative fuels
    - Coordinated motor, braking, transmission
    - Continuously varying transmission control
    - ABS, regenerative braking, etc…
- Environmental monitoring
  - Global warming
  - Environmental observation instrumentation, control
- Agriculture and ecology
  - Herd health monitoring
  - Remote veterinary care
  - Crop condition monitoring
- Emergency response
  - Rescue robotics
  - Command and control

Photo Credits: Boeing, GM, Medtronic
Closing the loop around combined behaviors…

**Control Software**

- Latency
  - Coordination Mode, Thread switching
  - Periodic calculation
  - Dynamic scheduling, resource management
  - Execution Rate
  - Voltage scaling

**Physical/Biological/Engineered System**

- Sensing
- Actuation
- Phase
- Stability
- Energy production, consumption
- Frequency
- Energy Management

**Hardware Platform**

- Clock rate
- Processing and Networking
- **Latency**
The Computer Science View

Processor  Memory

State

Behavior (Discrete dynamics)

Interaction

Automata Theory
Temporal Logic
Process Algebra

Courtesy: University of California Berkeley
Needed Interdisciplinary Science: Example from Hybrid Systems

What are Hybrid Systems?

Model of dynamics
Model of computation
Software execution
Framework

Courtesy: University of California Berkeley
What will it take?

Science and technology for open, interoperable systems that deeply integrate the cyber and physical and produce predictable behavior

- Control theory
- Networking
- Real time systems
- Logics and formal methods for verifying system behavior
- ...

A CPS educational strategy to create the 21st century CPS workforce that will be required

- Discrete mathematics and computer science
  - Automata, logics and formal methods, modeling and verification
  - Systems software, programming languages for CPS
- Continuous mathematics, physics, chemistry, biology…
  - ODEs, PDEs, fundamental laws of physics, …
- Hybrid discrete/continuous systems
The CPS Virtual Organization
Building CPS Community
Spontaneously Emerging CPS Research Community

IEEE/ACM CPSWeek and ESWEEK

- 2008
  - CPSWeek 2008, St. Louis
    - IEEE RTAS, ACM HSCC, IEEE ISPN
    - CPS Keynote: J. Wing
  - ESWEEK 2008, Atlanta
    - Turing Award Lecture (Edmund M. Clarke, E. Allen Emerson, Joseph Sifakis)
- 2009
  - CPS Week 2009, San Francisco
    - First CPS Forum
    - Mixed-Criticality Architecture Requirements (MCAR) Workshop
  - ESWEEK 2009, Grenoble
- 2010
  - CPSWeek 2010, Stockholm – ACM SIGPLAN LCTES joins CPSWeek
  - ESWEEK 2010, CODES/ISSS/DATE/EMSOFT

Other outreach:

- CPS Exposition – Rayburn Senate Building
- Other conferences: IEEE IROS, ACC, CDC, …
- NASA Aviation Safety Conference
- FDA Medical Device Interoperability Workshop
Industry/ Academy Perspective


- Boeing
- BAE Systems
- Bosch
- Ford
- Lockheed-Martin
- National Instruments
- Raytheon
- SRC
- Toyota
- United Technologies

- UC Berkeley,
- CMU,
- GMU,
- U.Penn,
- UIUC
- UT Austin
- U.Arizona
- UMD
- U.Virginia
- Vanderbilt
Workshop Recommendations

1. **Establish a National CPS Initiative as a private-public partnership**
   A unique aspect of CPS is that results are so immediately relevant to near-term industry products that industry wants to participate in pre-competitive research.

2. **Structure the Initiative around industry defined Integrative Technology programs**
   Integrative technologies, such as high-confidence/trustworthy CPS design, are novel combination of innovations from several scientific disciplines. Integrative Technology programs will be the incubators for a new CPS discipline.
Workshop Recommendations

3. **Establish an Annual CPS Research Forum**
   The loose network of collaborative research programs support an open annual CPS Research Forum that informs stakeholders about emerging industry needs for specific integrative technologies, established testbeds, achieved technology breakthroughs, progress in foundations, and national, international trends.

4. **Develop a National CPS Research Infrastructure**
   The CPS Research Infrastructure facilitates the transition of results among academy and industry research groups. Core components of the infrastructure include open, quality controlled repositories for challenge problems, tools and software, open experimental platforms, collaboration platforms, and education materials that are accessible through a web portal.
NSF Defined Objectives

- The objective of the CPS-VO is to actively build and support the multidisciplinary community needed to underpin this new research discipline and enable interagency and international collaboration on CPS.

- In support of the CPS-VO, Vanderbilt (PI: Christopher P. van Buskirk) will work with the community to develop strategies and mechanisms to facilitate:
  - **Community building**: interaction and exchange among CPS researchers across a broad range of institutions, programs and disciplines,
  - **Collaboration**: sharing knowledge, experimental tools, platforms and simulators
  - **Technology transfer and translational research**: information exchange between academy and industry, shared testbeds and industry defined scenarios
  - **International collaboration**: collaboration with international research groups, networks of excellence such as ARTISTDESIGN in Europe
CPS-VO Portal

- Principles & Services
  - Community controlled
  - Services for collaborative activities
  - Support for SIGs
  - Industry academy interactions
  - Built on open source framework
  - Home for the community’s historical reference materials
  - Calendar of upcoming events
  - Discussion forums and instant messaging
  - Community members list and matchmaking
Community Calendar & Discussion Forums
Community Directory
CPS-VO Repositories

Repository

- **Challenge problems**: (leveraging DoD SPRUCE repository)
- **Solutions**: models, software, tools, HW design,…
- **Education material**: modules, courseware, curriculum
- **Semantic Repository**: support for creating, processing, retrieving, integrating and aggregating information
Semantic Repository

Building upon Stockroom technologies (AFRL)
Community Building

- Help relating and combining ideas across disciplines
- Facilitate CPS Community Forums, such as ICCPS, CPSWEEK, National CPS PI Meeting
- Foster international collaboration to establish standards, education programs, shared vocabularies
NSF expects that Open Experimental Platforms (OEP) will be created by the CPS community. Examples for high impact platforms are Emulab (University of Utah), DETER (USC-ISI and UC Berkeley), C2 Wind Tunnel (Vanderbilt)

The CPS-VO Repository will be prepared for hosting/integrating web accessible OEPs
Management Structure

CPS-VO Governing Boards:

1. **Industrial Executive Board (Chair: Don C. Winter, Boeing)**
   a. advise the CPS-VO regarding emerging CPS research challenges across industrial sectors,
   b. advise the directions in extending the CPS-VO infrastructure components
   c. evaluate progress in the CPS-VO and in the CPS-VO infrastructure from the point of view of industrial competitiveness

2. **Academic Executive Board (Chair: George Pappas, Upenn)**
   a. identify and formulate fundamental scientific challenges across disciplines
   b. evaluate progress in the scientific foundations, intellectual directions and problem understanding
   c. evaluate progress in the CPS-VO operation, including the infrastructure, collaborations, and education

3. **Outreach Board**
   a. conduct community-based technology assessment
   b. explore and coordinate interactions with academic institutions, industry and government as appropriate
Agency presentations

Project briefings followed by PI panel (all major CPS projects)

Poster sessions

Conversation sessions with industry, agencies

Late night “birds of a feather” meetings for SIGs
Summary

- CPS represents the “center of gravity” in NIT applications in the future
- Significant application pull: huge need for a shared S&T core
- Need: Systems Science of Security
- CPS Virtual Organization has important role in evolving the science and technology base and shared understanding
- 1st National CPS PI Meeting August 10-12, Arlington, VA
Conclusion
Retrospective/ Prospective

- Busy, productive few years

- CPS is now in the national and international discourse
  - Federal NIT R&D strategic planning
  - “America Competes” legislation
  - EU-US engagement

- Continually developing agenda
  - S5 research
  - Interagency roadmap
  - Industry-University engagement
  - CPS Education Workshop, Aug 12-13
  - “Extreme Manufacturing” Workshop, Oct 2010
  - USCAR workshop: fault tolerant automotive CPS, Oct 2010
Thank you!