



Update of National Perspective on Cyber-Physical Systems

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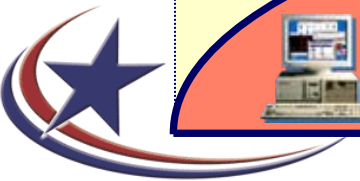
Overview

- **What are Cyber-Physical Systems?**
- Economic context
- Technical context
- Interagency context



Cyber Physical Systems

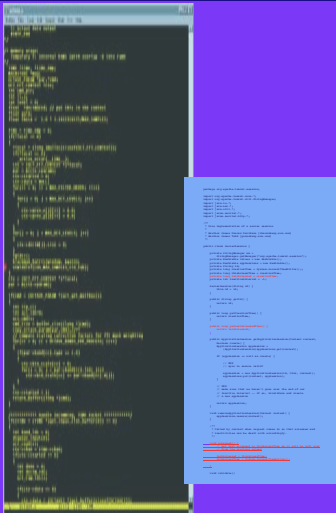
- Two types of computing systems
 - Desktops - servers, PCs, and notebooks
 - Embedded
- The next frontier
 - Mainframe computing (60's-70's)
 - Large computers to execute big data processing applications
 - Desktop computing & Internet (80's-90's)
 - One computer at every desk to do business/personal activities
 - Embedded computing (21st Century)
 - "Invisible" part of the environment
 - Transformation of industry
- Number of microprocessor units per year
 - Millions in desktops
 - Billions in embedded processors
- Applications:
 - Automotive Systems
 - Light and heavy automobiles, trucks, buses
 - Airspace Systems
 - Airplanes, space systems
 - Consumer electronics
 - Mobile phones, office electronics, digital appliances
 - Health/Medical Equipment
 - Patient monitoring, MRI, infusion pumps, artificial organs
 - Industrial Automation
 - Supervisory Control and Data Acquisition (SCADA) systems for chemical and power plants
 - Manufacturing systems
 - Defense
 - Source of superiority in all weapon systems



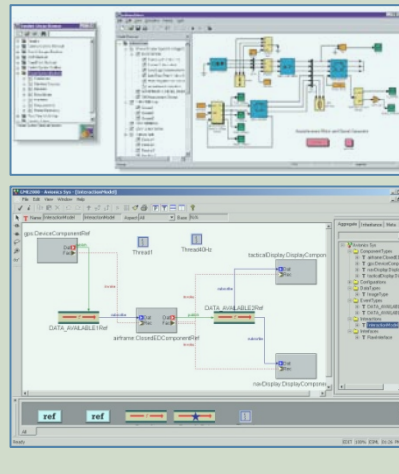


Why is CPS Hard?

Software



Control



Systems



Crosses Interdisciplinary Boundaries

- Disciplinary boundaries need to be realigned
- New fundamentals need to be created
- New technologies and tools need to be developed
- Education need to be restructured



Why Is CPS Significant?

- Building systems that integrate computational and physical objects requires new systems science foundations.
 - Fusion of physical and computational sciences
- The share of value of embedded computing components in the next five years grows to:

– Automotive and airspace systems	30-40%
– Health/Medical equipment	33%
– Industrial automation	22%
– Telecommunications	37%
– Consumer electronics and Intelligent Homes	41%
- *CPS are the basic engine of innovation for a broad range of industrial sectors.*
 - *This is the technology that transforms products, creates new markets and disrupts the status-quo.*

Cyber Physical Systems are the foundations for the Systems Industry





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Calibrating U.S. Competitiveness



- National Academies study: **“Rising Above The Gathering Storm: Energizing and Employing America for a Brighter Economic Future”**

http://www7.nationalacademies.org/ocga/testimony/Gathering_Storm_Energizing_and_Employing_America2.asp

Addressing U.S. Competitiveness



- American Competitiveness Initiative announced:
<http://www.whitehouse.gov/stateoftheunion/2006/aci/>
 - Calls for a doubling over 10 years of the investment in three Federal agencies — NSF, DOE/SC, and NIST — that support basic research programs in the physical sciences and engineering
 - All three are NITRD Program member agencies; received 2007 budget increases that exceed the percentage increase in the overall NITRD budget
 - NSF: 12% increase
 - DOE/SC: 35% increase
 - NIST: 10% increase
 - Collective increase for ACI agencies is \$186 million (17% above 2006 estimates)
 - Increase in ACI agency budgets accounts for over 85% of the overall NITRD Program budget increase for 2007
 - These agencies' physical sciences and engineering R&D will play a key role in generating technical advances in IT systems



CPS is a New Focus in EU

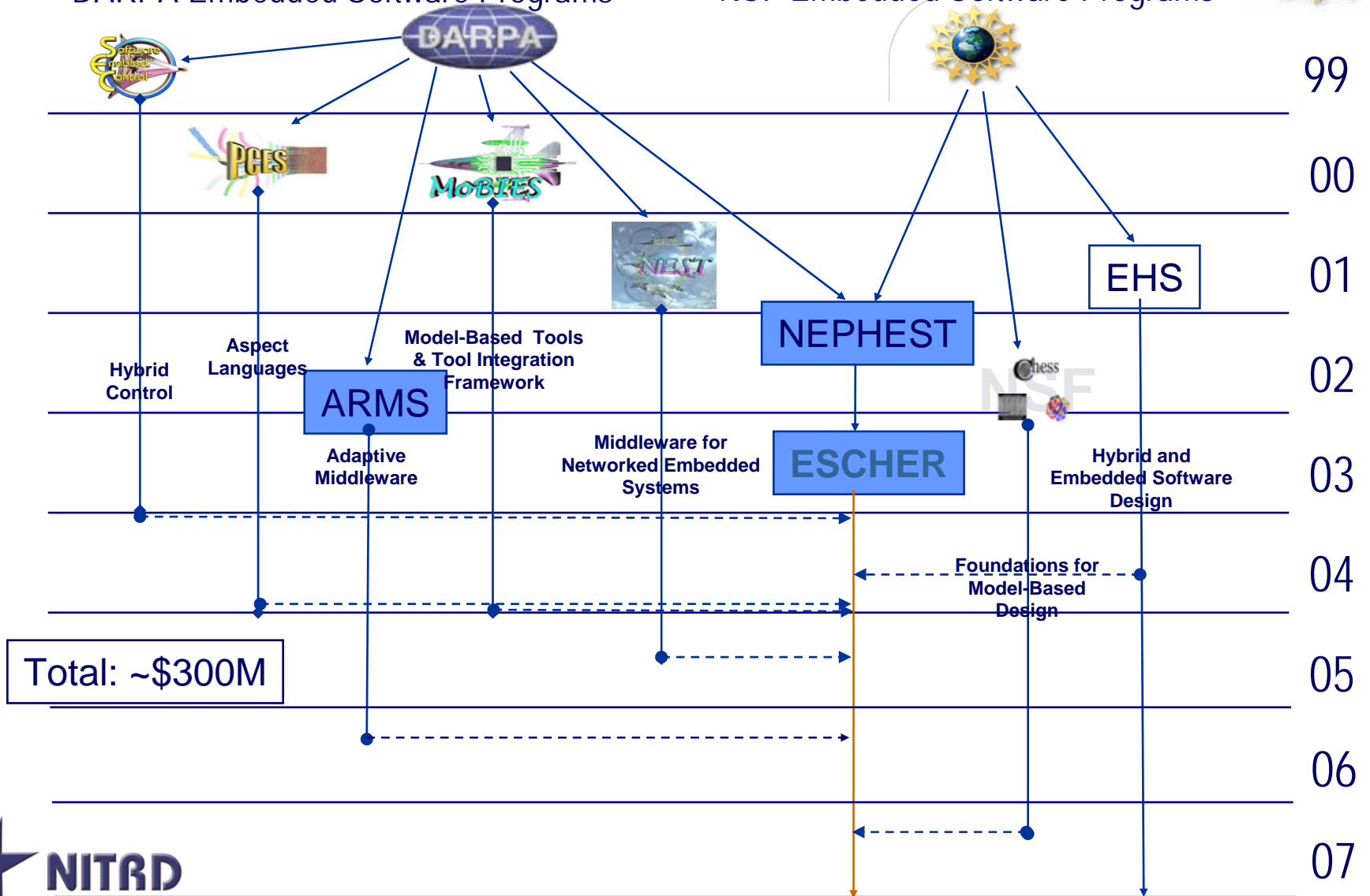
- Announced November 2006: FP7 ICT work programme; 9B€ over 2007-2013
- **ARTEMIS, 3B€ over 2007-2013 (7 years)**
 - Embedded systems investment
 - Backbone of European Research Area for Embedded Systems, <http://www.artemis-office.org/>
 - Strategic Research Agenda (SRA)
 - Joint Technology Initiative (JTI)
 - Embedded systems education and curriculum
- “High-Level Group”
 - CEOs: ABB, Airbus, Nokia, Parades, British Telecom, COMAU, Philips, Bosch, Continental Teves, Daimler/Chrysler, ST Microelectronics, Symbian, Ericsson, Finmeccanica, Telenor, Thales, IMEC, Infineon
 - Universities and national research labs: across EU, major universities and research institutes participate
- Joint public (EU and national) and private funding, approximately 50/50

US Research in CPS is Decreasing

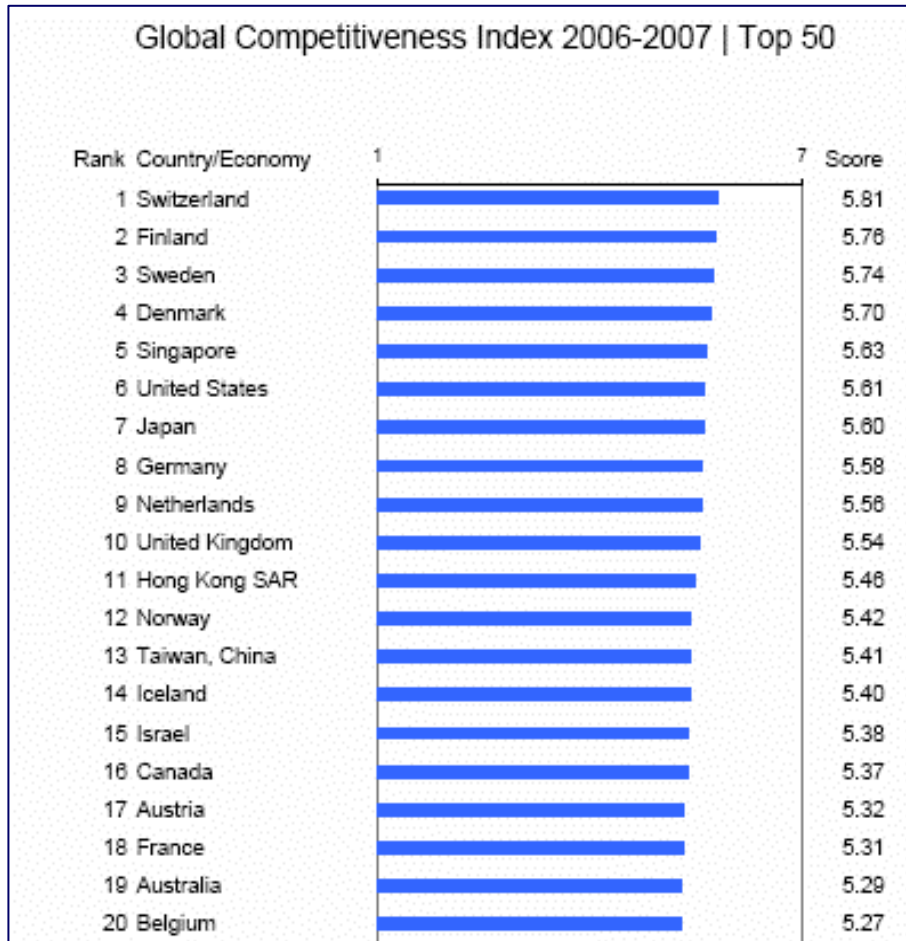


DARPA Embedded Software Programs

NSF Embedded Software Programs



Economic Context: Latest Data



- US dropped from first to sixth
- Twelve out of the first twenty are EU member states
- The first four are EU member states
- EU increases 75% of R&D investment in Information and Comm. Technology research by 2013



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Example: Health Care and Medicine



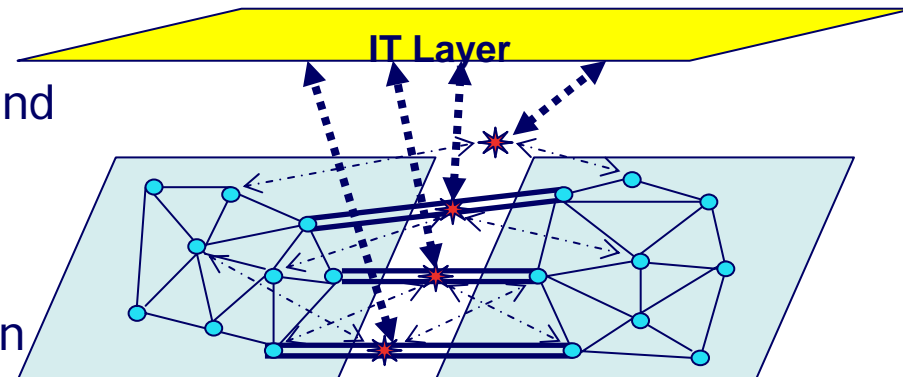
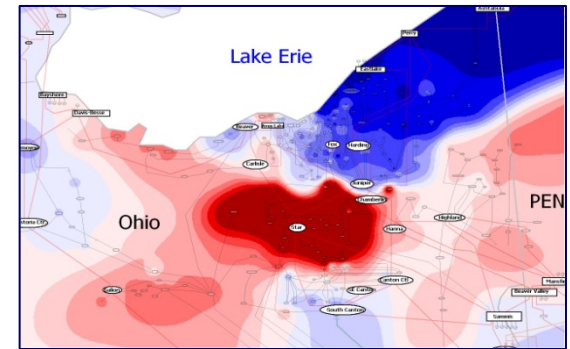
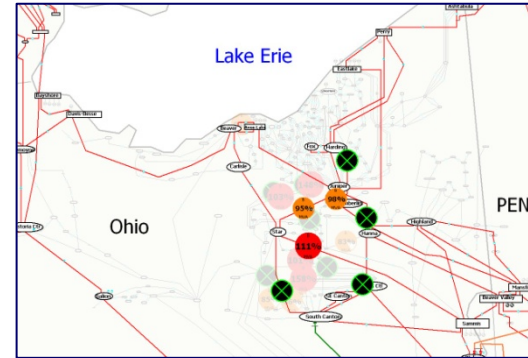
- National Health Information Network, Electronic Patient Record initiative
 - Medical records at any point of service
 - Hospital, OR, ICU, ..., EMT?
- Home care: monitoring and control
 - Pulse oximeters (oxygen saturation), blood glucose monitors, infusion pumps (insulin), accelerometers (falling, immobility), wearable networks (gait analysis), ...
- Operating Room of the Future (Goldman)
 - Closed loop monitoring and control; multiple treatment stations, plug and play devices; robotic microsurgery (remotely guided?)
 - System coordination challenge
- Progress in bioinformatics: gene, protein expression; systems biology; disease dynamics, control mechanisms



Example: Electric Power Grid



- **Current picture:**
 - Equipment protection devices trip locally, reactively
 - Cascading failure: August (US/Canada) and October (Europe), 2003
- **Better future?**
 - Real-time cooperative control of protection devices
 - Or -- self-healing -- (re-)aggregate islands of stable bulk power (protection, market motives)
 - Ubiquitous green technologies
 - Issue: standard operational control concerns exhibit wide-area characteristics (bulk power stability and quality, flow control, fault isolation)
 - Technology vectors: FACTS, PMUs
 - Context: market (timing?) behavior, power routing transactions, regulation



Example: Automotive Industry

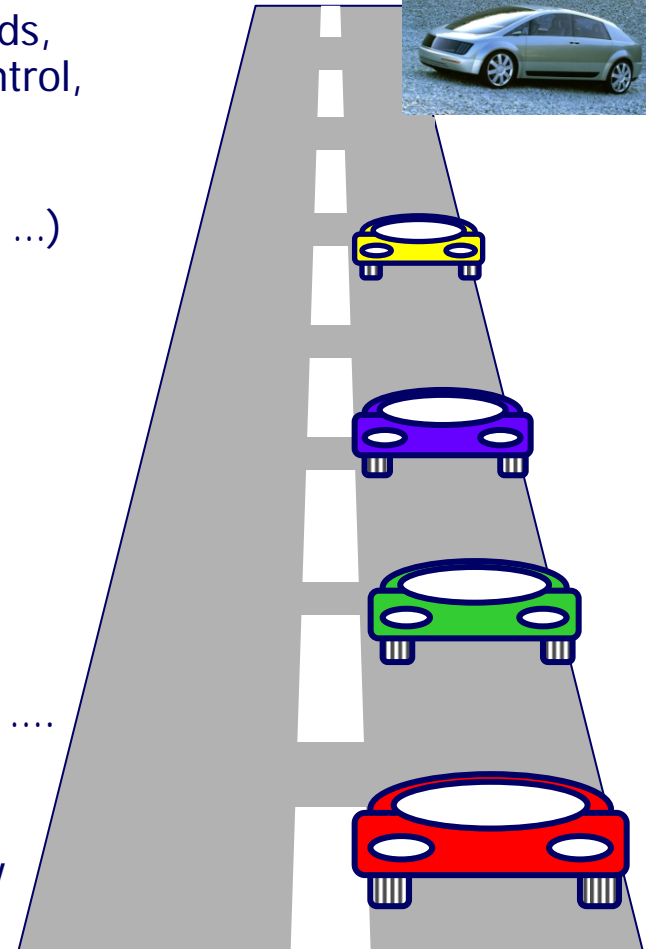


- **Current picture**

- Largely single-vehicle focus
- Integrating safety and fuel economy (full hybrids, regenerative braking, adaptive transmission control, stability control)
- Safety and convenience “add-ons” (collision avoidance radar, complex airbag systems, GPS, ...)
- Cost of recalls, liability; growing safety culture

- **Better future?**

- Multi-vehicle high-capacity cooperative control roadway technologies
- Vehicular networks
- Energy-absorbing “smart materials” for collision protection (cooperative crush zones?)
- Alternative fuel technologies, “smart skin” integrated photovoltaics and energy scavaging, ...
- Integrated operation of drivetrain, smart tires, active aerodynamic surfaces, ...
- Safety, security, privacy certification; regulatory enforcement



- **Perennial context: Time-to-market race**

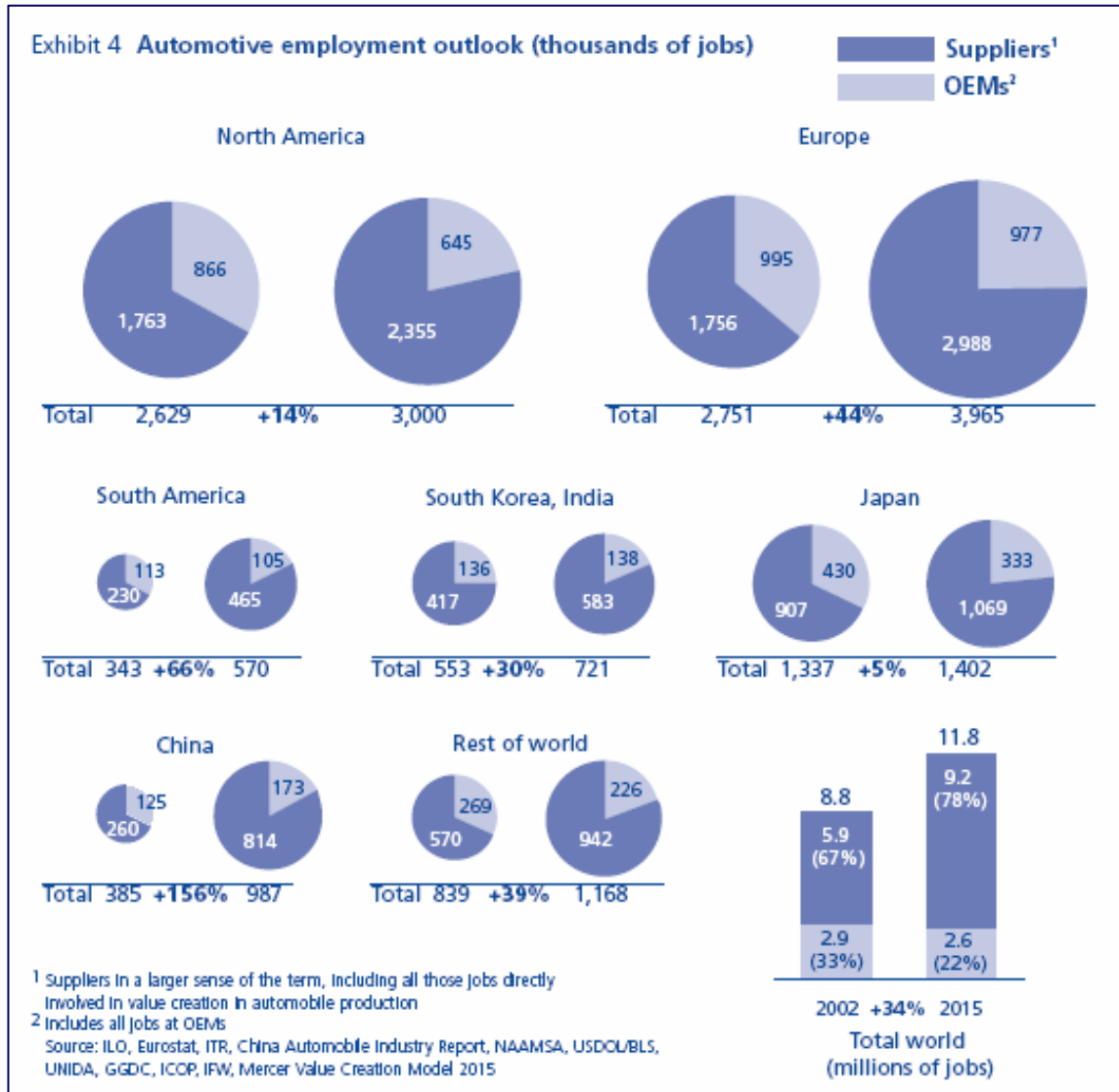
Economic Weight of the Automotive Sector



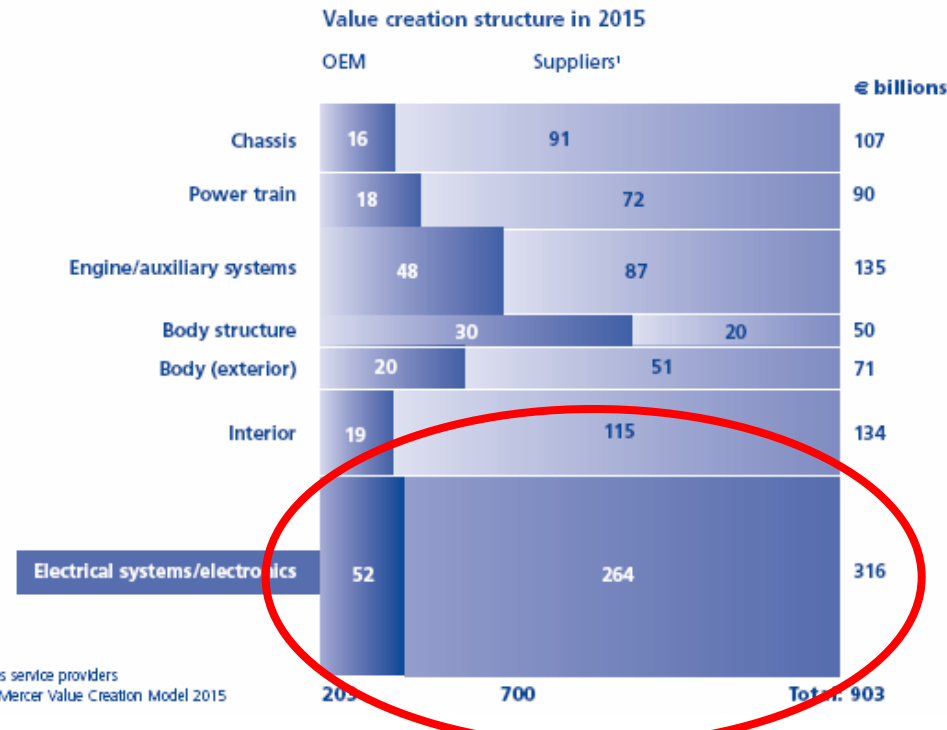
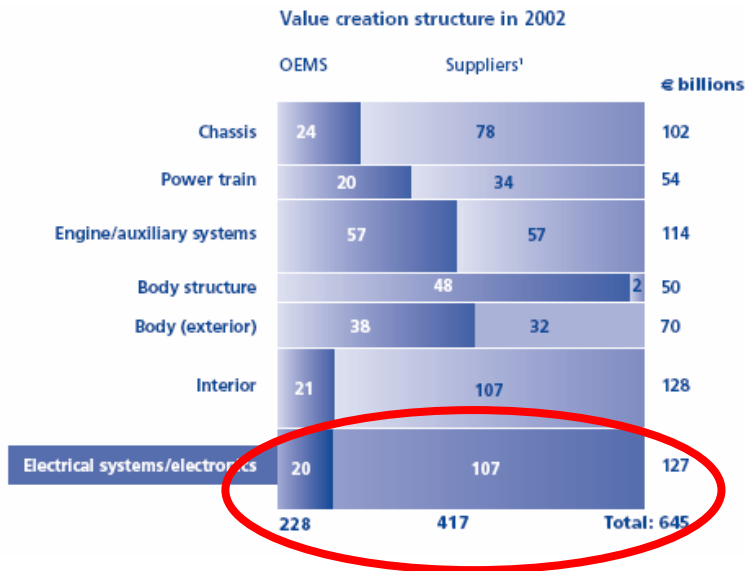
	2006	2015
• Share of World-Wide GDP:	15%	
• Predicted GDP change		
– Total	\$978B	\$1,174B
– USA (NAFTA)	\$295.1B	\$347.1
– EU	\$265.2	\$413.4
• Growth data		
– Capital spending		\$2,600B
– Jobs		+3M
– Number of light vehicle units	57M	76M



Worldwide Employment Statistics



Value Creation





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Home of Activities:

NITRD High Confidence Software and Systems
Coordinating Group

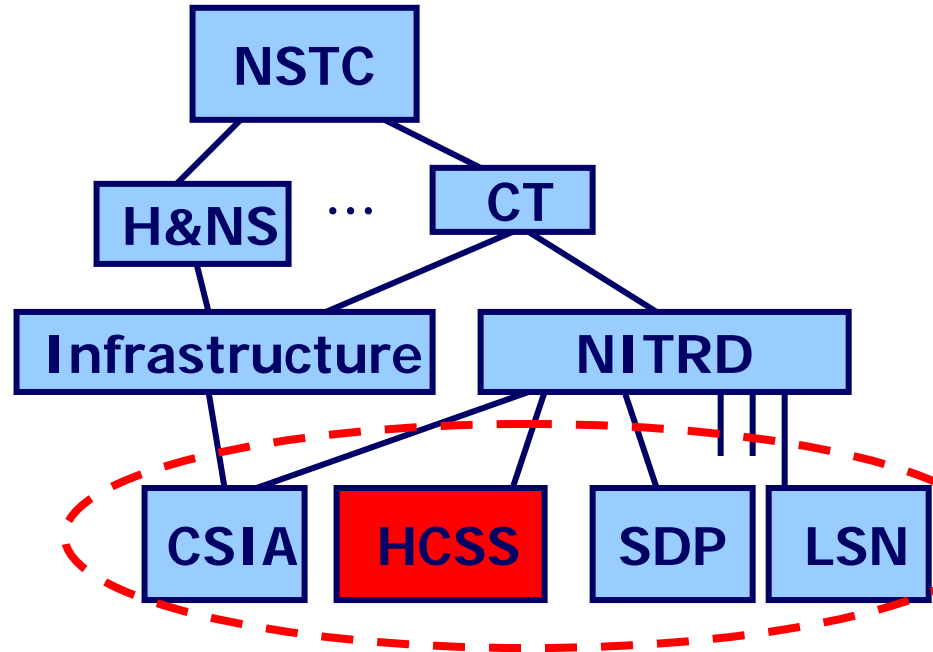
Chair: Dr. Helen Gill, NSF



Organizational Context: R&D Coordination for High Confidence Software and Systems



- NSTC Committee structure
- CT – Committee on Technology
 - Networking, IT R&D (NITRD)
 - Subcommittee, “blue book”
 - Infrastructure Subcommittee
 - CIP R&D Planning
 - National CIP R&D Plan
 - CIIP R&D Plan



- **NITRD R&D Planning - High Confidence Software and Systems (HCSS) Coordinating Group**
- Software Design and Productivity Coordinating Group
- Large Scale Networking (LSN) Coordinating Group
- Cyber Security and Information Assurance (CSIA) Interagency Working Group



High-Confidence Software and Systems (HCSS) Agencies

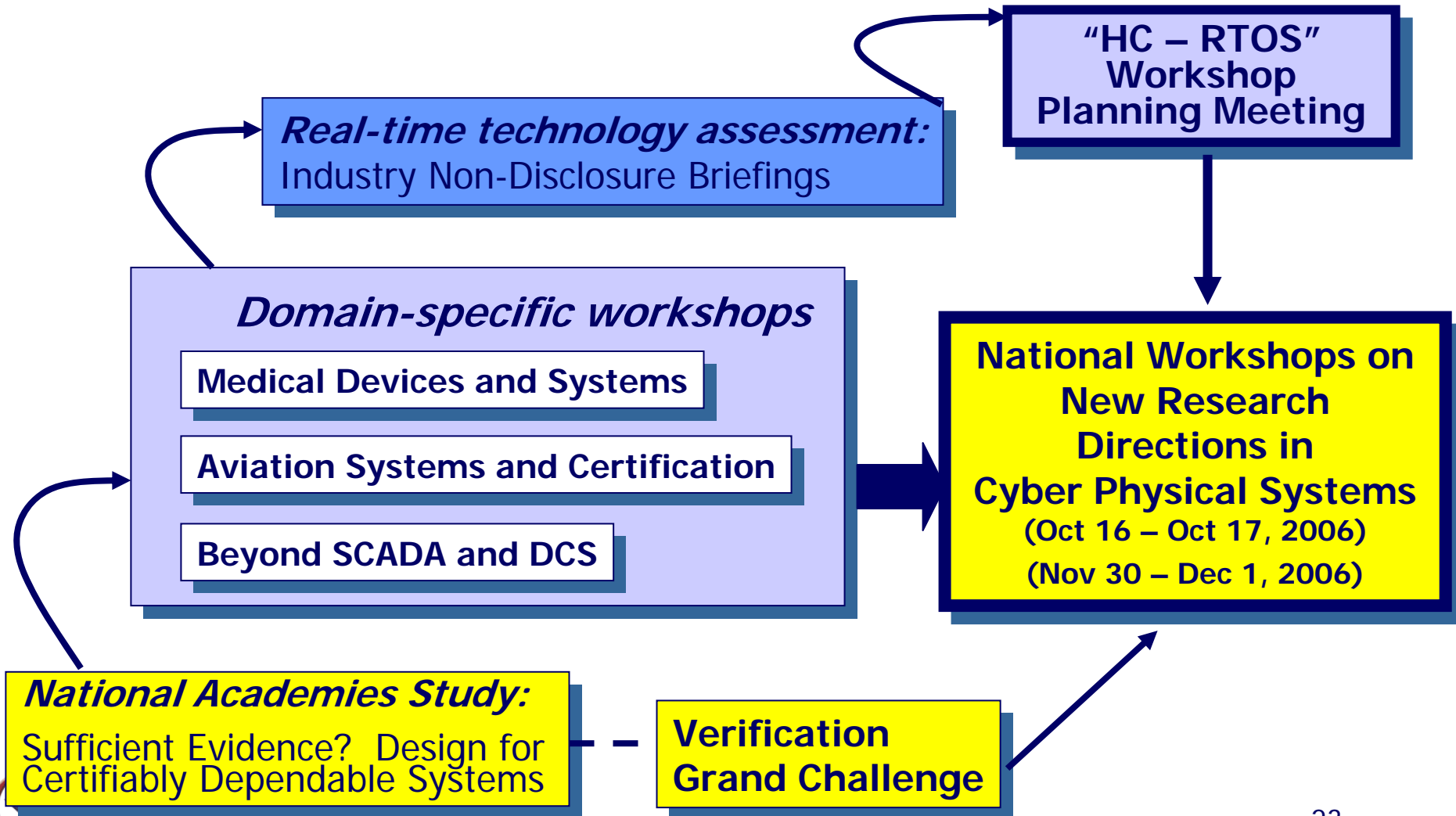


- Air Force Research Laboratories and Air Force Office of Scientific Research*
- Army Research Office*
- Department of Defense/ OSD
- Defense Advanced Research Projects Agency
- Department of Energy
- Department of Homeland Security
- Federal Aviation Administration*
- Food and Drug Administration*
- 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

Structure of Needs Assessments



Technology Substrate for CPS



- NSF Cyber Physical Systems (CPS) exploratory (seedling) activities
 - Community-led planning, NSF CISE and ENG directorates
 - FY 2006: CPS planning studies commissioned from senior academics
 - FY 2006: Evidential Tool Bus – exploratory research (Rushby, SRI)
 - Discussions with corporate VPs, CEOs initiated
 - CPS workshops:
 - NSF CPS Community Planning Meeting, Arlington, VA, July 27-28, 2006
 - NSF CPS National Meeting, Austin, TX, October 16-17, <http://varma.ece.cmu.edu/cps/>
 - NSF HCSP CPS Research Needs and Roadmap Meeting, Alexandria, VA, November 29-30, 2006 <http://www.isis.vanderbilt.edu/HCSP-CPS/>
 - Domain Specific Workshops
- FY 2007 Computer Systems Research announcement, NSF 07-504; http://www.nsf.gov/publications/pub_summ.jsp?ods_key=nsf07504
 - ***Cyber-Physical Systems thematic area (seedling)***
 - *Related topic: Virtualization for Configuration Management*



Needs Assessments in Specific Areas

- High Confidence Medical Device Software and Systems (HCMDSS),
 - Planning Workshop, Arlington VA, November 2004, <http://www.cis.upenn.edu/hasten/hcmdss-planning/>
 - National R&D Road-Mapping Workshop, Philadelphia, Pennsylvania, June 2005, <http://www.cis.upenn.edu/hcmdss/>
- Aviation Software Systems for the Second Century of Flight: Design for Certifiably Dependable Systems (HCSS-AS) (NSF, AFRL, NASA, FAA)
 - Planning Workshop, Seattle, WA, November 9-10, 2005
 - National R&D Road-Mapping Workshop, Alexandria, Virginia, October 5-6, 2006
- High Confidence Critical Infrastructures: “Beyond SCADA: Networked Embedded Control Systems” (NSF, NIST, NSA)
 - US Planning Workshop, Washington, DC, March 14-15, 2006
 - ***US National R&D Road-Mapping Workshop, Pittsburgh, Pennsylvania, November 8-9, 2006***



Concluding Remarks

- Cyber Physical Systems is an important inter-agency priority for American Competitiveness
- High Confidence Systems and Software (HCSS) is a good home for the interagency initiative. High confidence includes
 - Correct by construction
 - Fault resistant
 - Intrusion tolerant: graceful degradation even after successful attack
- Suggested Program in the model successful NSF ITRs at NSF, OXRs, NASA, DoE:
 - Large size Centers
 - Mid size Centers
 - GICUR (Government Industry Cooperative University Research)
 - UARC (University Affiliated Research Center)