Cyber-Physical Systems Research Charge

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Cyber-Physical Systems Summit
St. Louis, MO
24 April 2008

Smart Cars

Credit: PaulStamatiou.com

Cars drive themselves

A BMW is "now actually a network of computers"

[R. Achatz, Seimens, Economist Oct 11, 2007]

Credit: Dash Navigation, Inc.

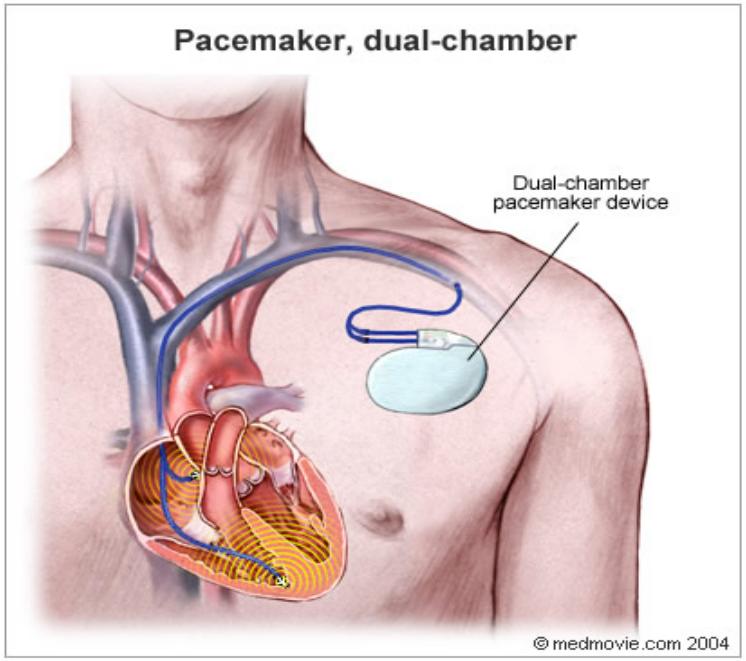
Dash Express: Cars are nodes in a network

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.]

Embedded Medical Devices

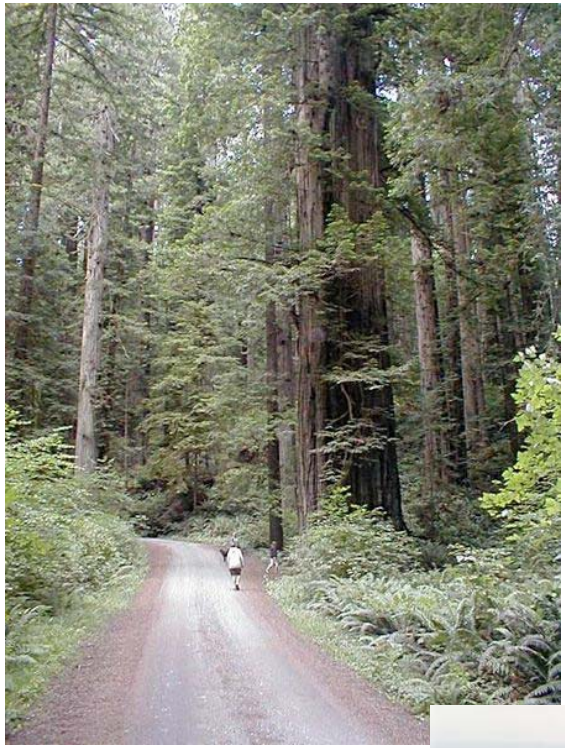


pacemaker

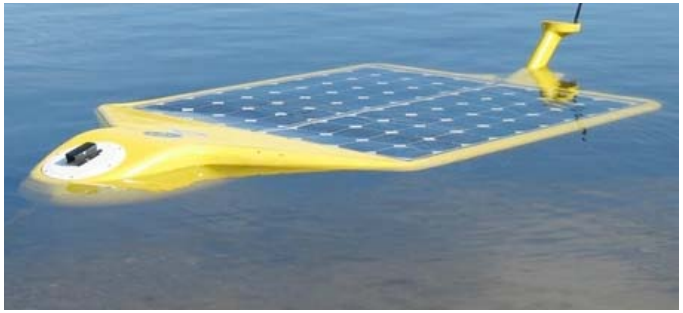
infusion pump

scanner

Sensors Everywhere



Sonoma
Redwood Forest



Credit: Arthur Sanderson at RPI

Hudson River Valley

Kindly donated by Stewart Johnston

smart buildings

Credit: MO Dept. of Transportation

smart bridges

Robots Everywhere

Credit: Honda

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

Credit: Paro Robots U.S., Inc.

At home: Paro, therapeutic robotic seal

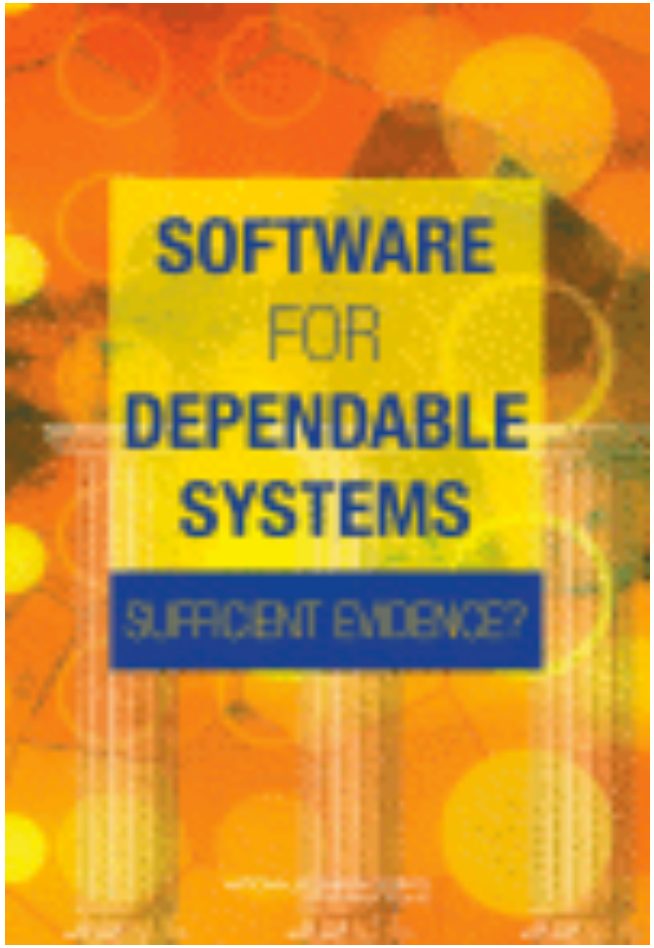
Credit: Carnegie Mellon University

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

At home: iRobot Roomba vacuums your house

CSTB National Academies Study

Software for Dependable Systems: Sufficient Evidence?
Daniel Jackson, Martyn Thomas, and Lynette I. Millett, Editors
May 9, 2007

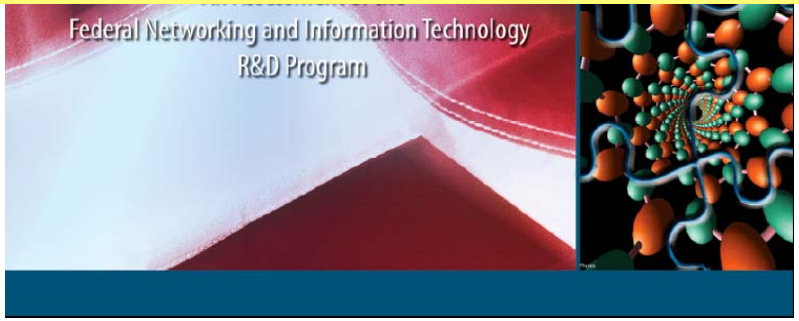


Credit: National Academy of Sciences

U.S Broader Research Agenda and Priorities

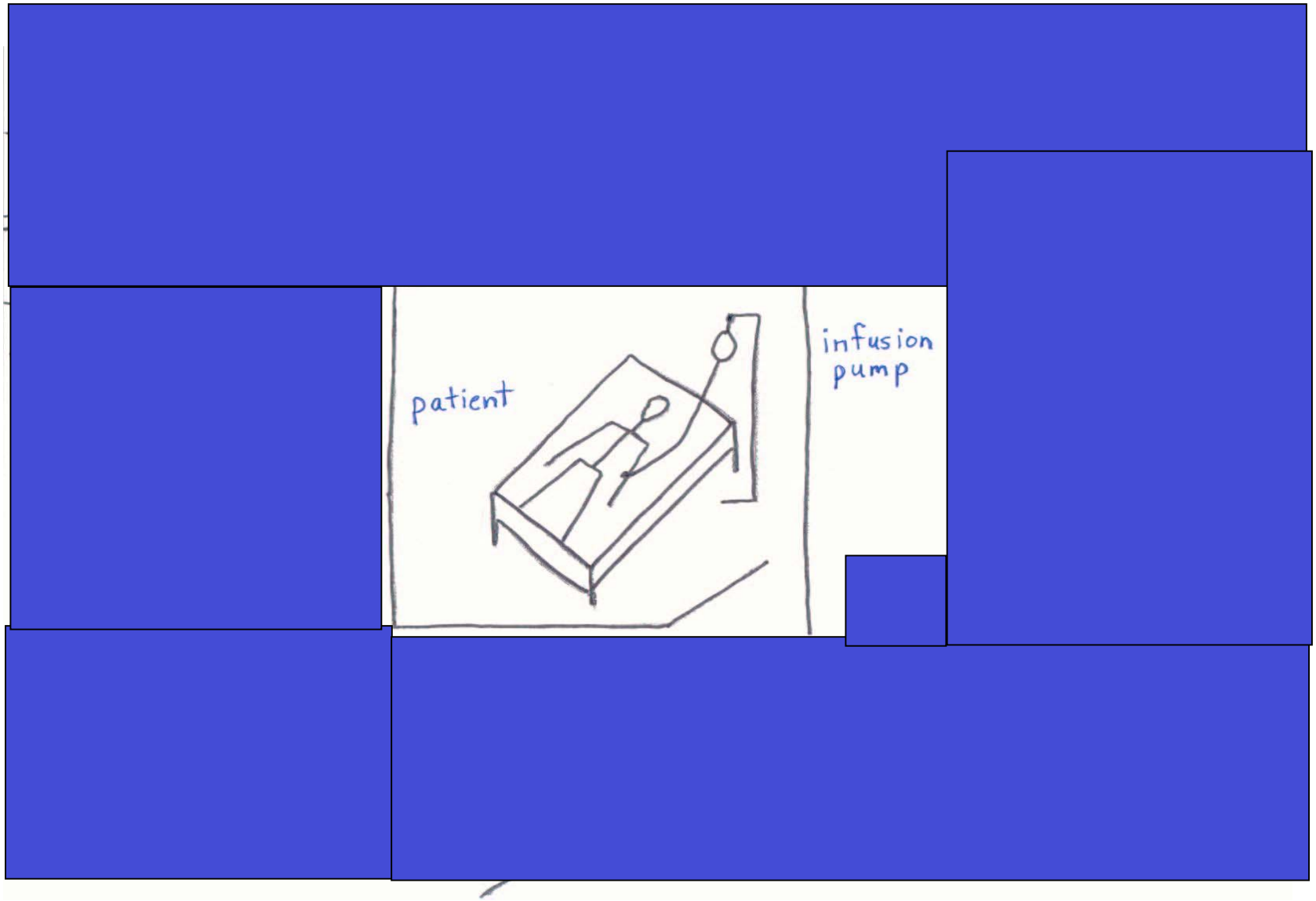
Dan Reed and George Scalise, editors
August 2007

#1 Priority: Cyber-Physical Systems
Our lives depend on them.



Credit: http://www.ostp.gov/pdf/nitrd_review.pdf

This is Not Science Fiction



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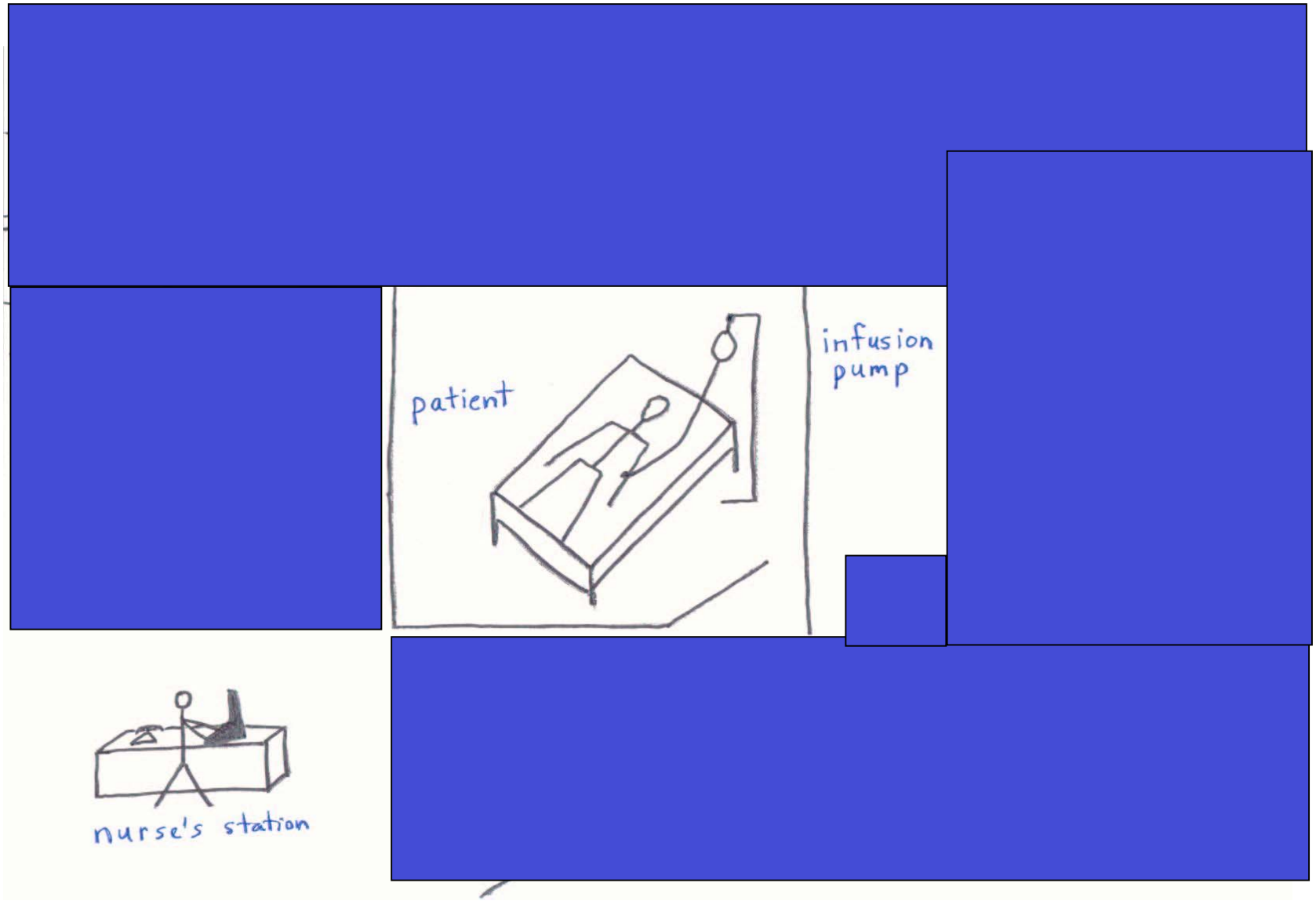

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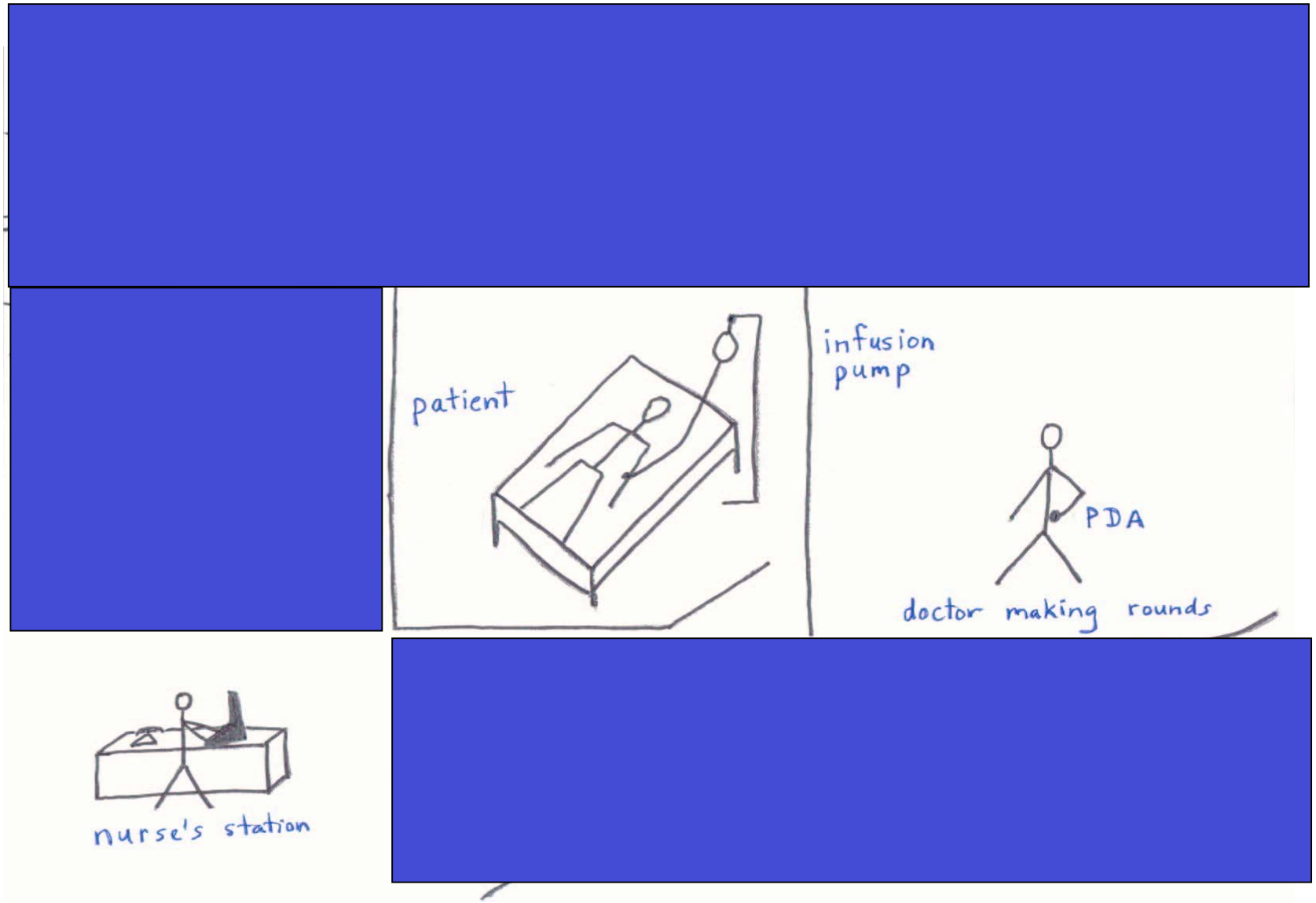

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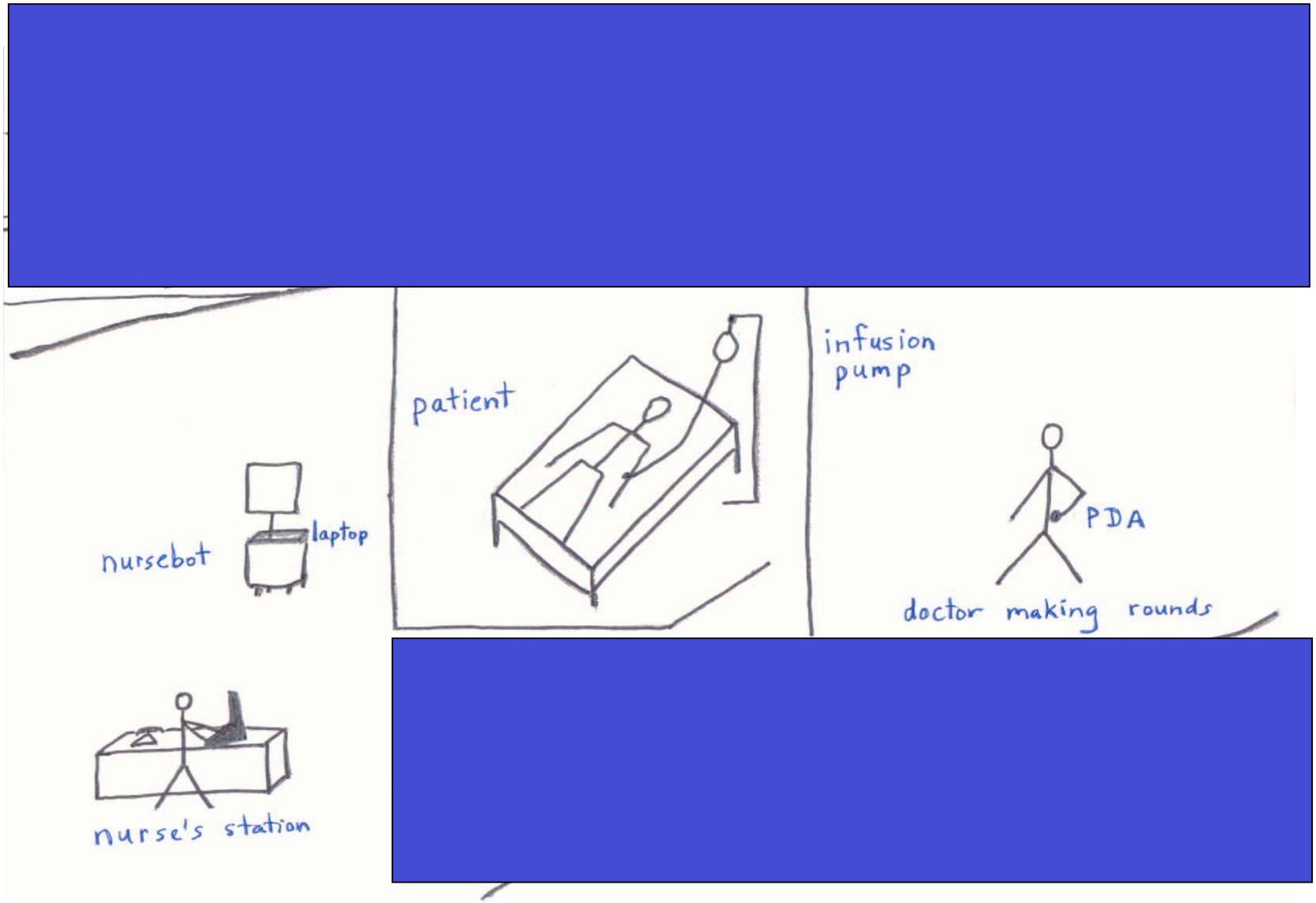

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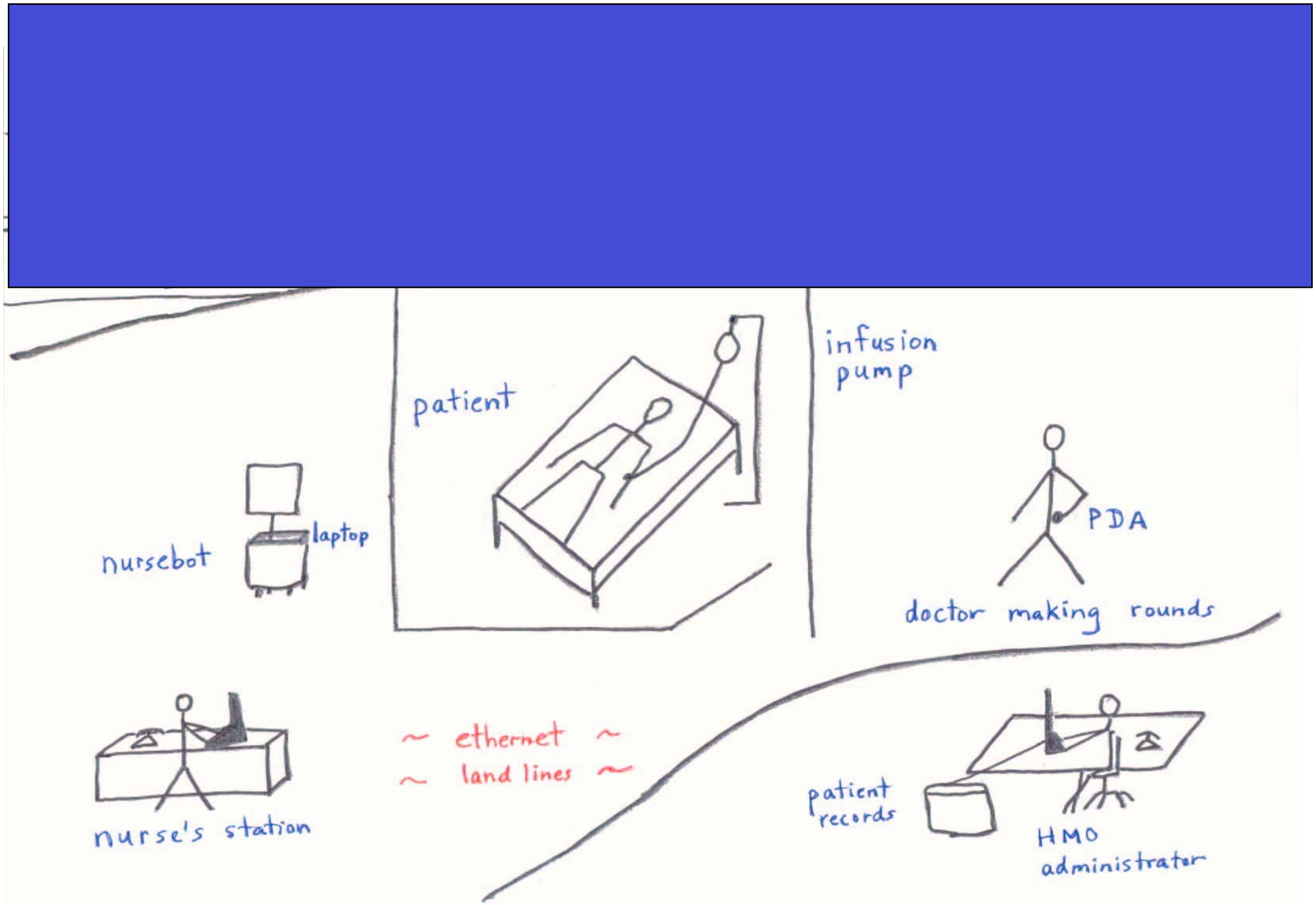

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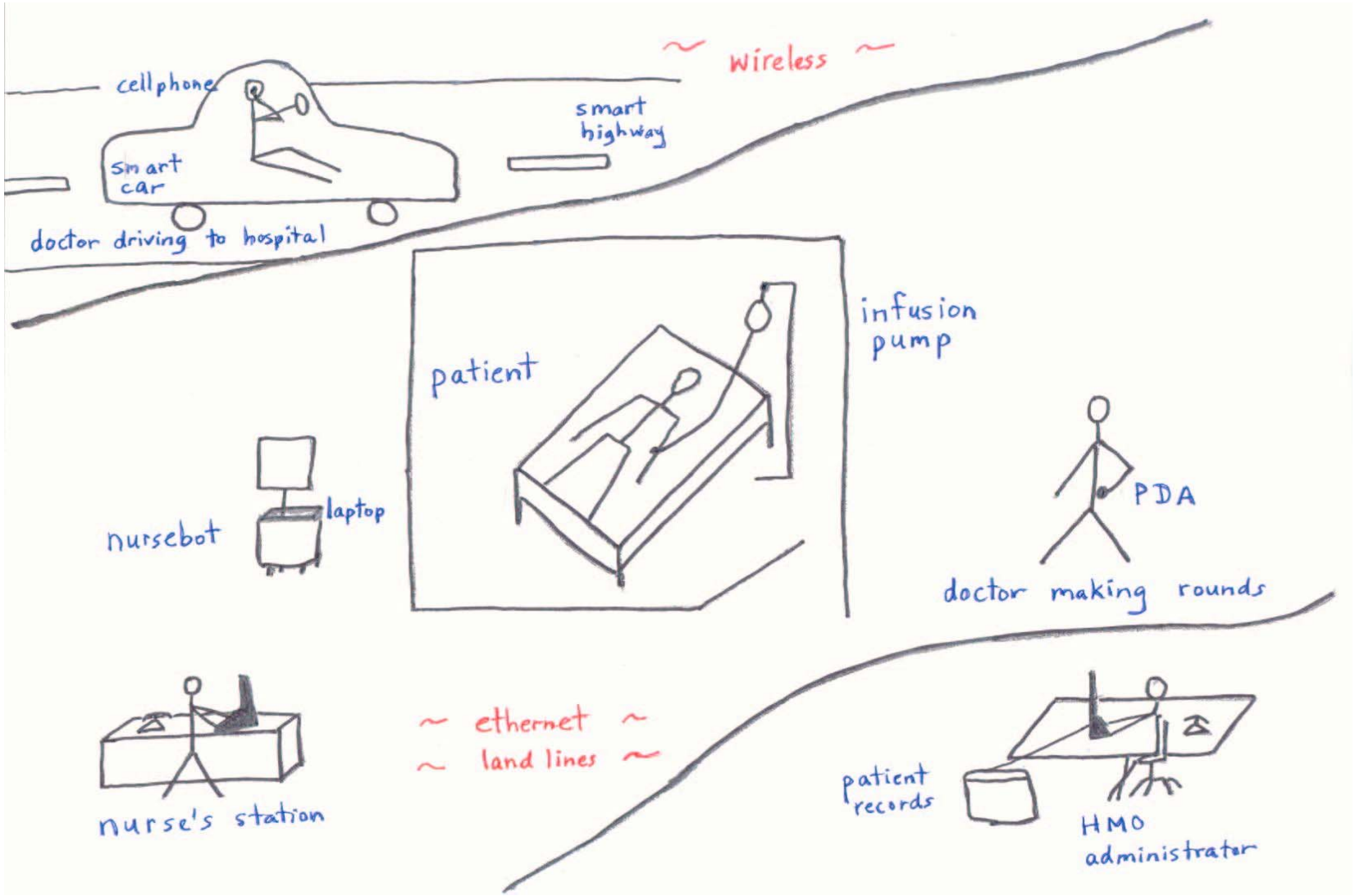

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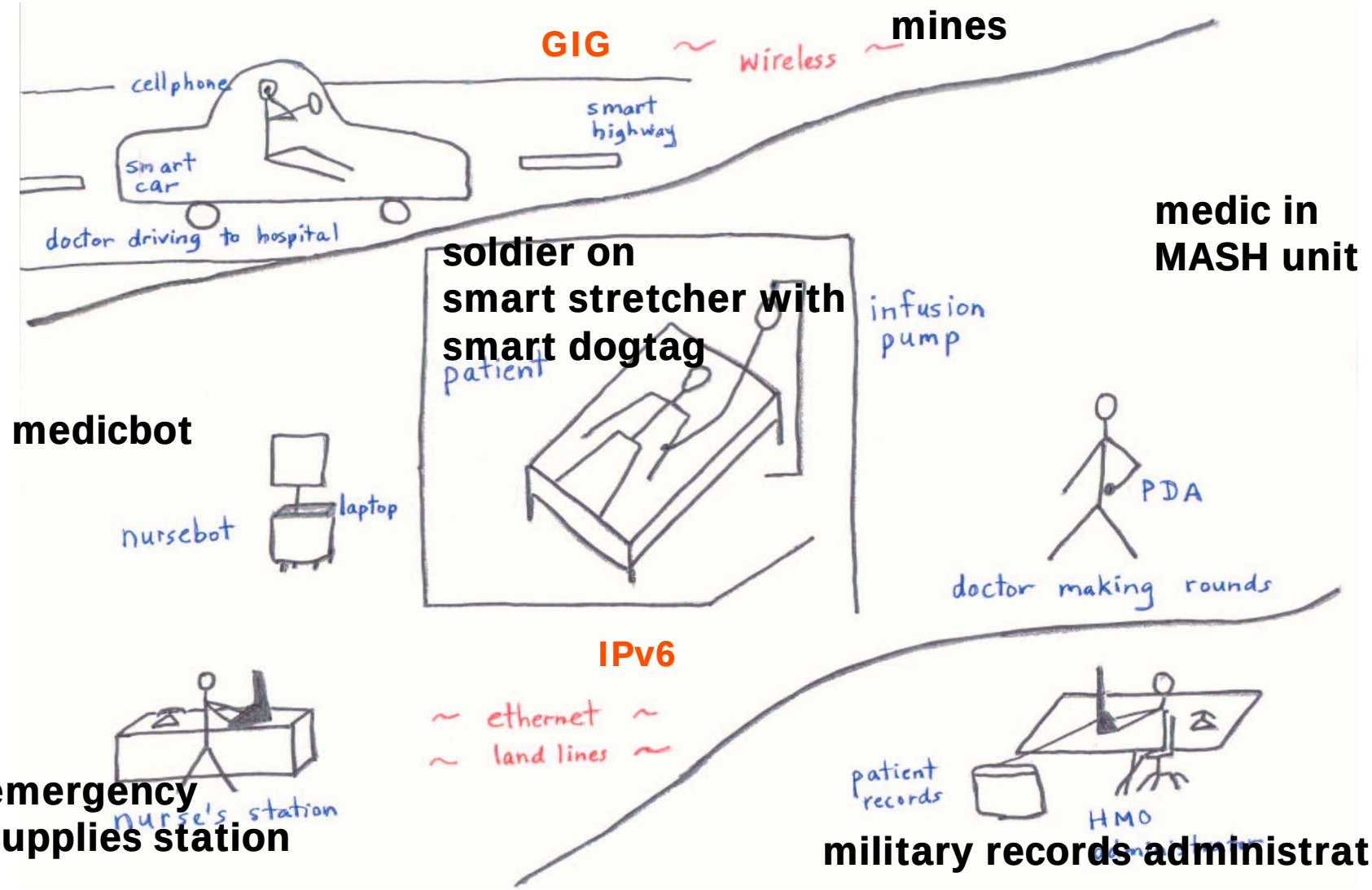


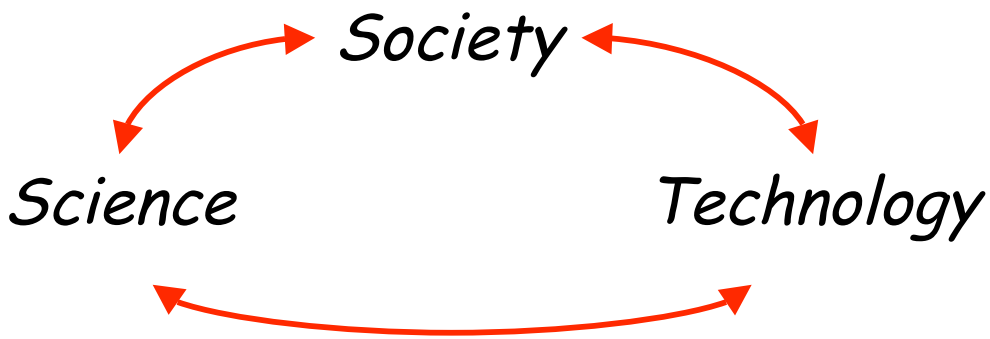
State of the Art

- 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



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

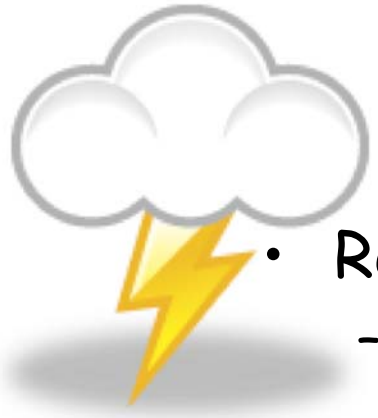
Technical Challenge

- (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.

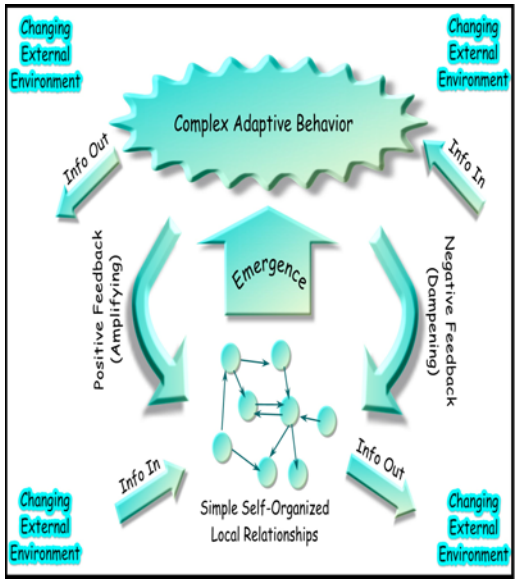
Fundamental Scientific Challenges

- 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
  - …

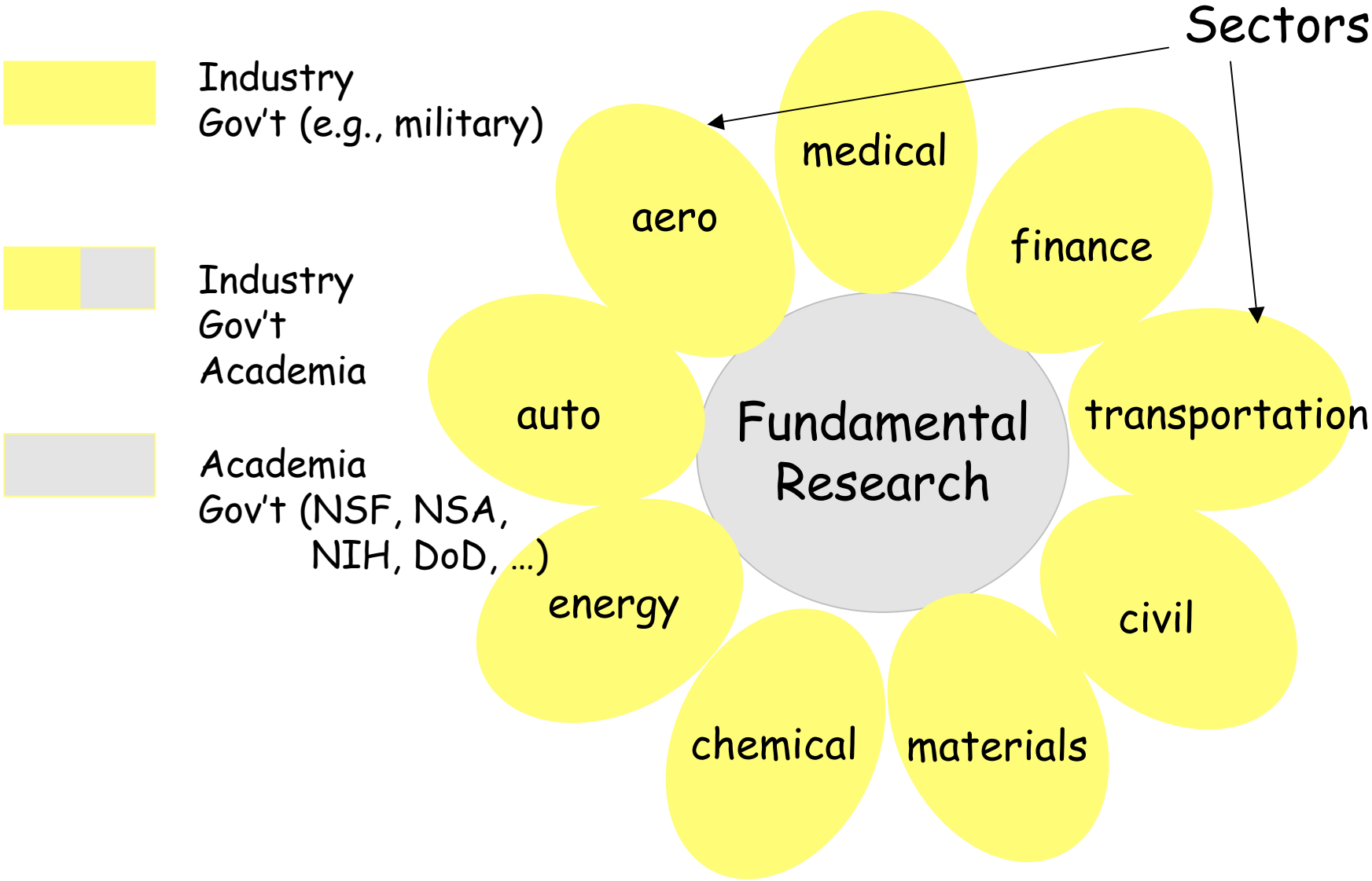
Broader Implications

- 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



New Models for Academia-Industry-Government Partnership

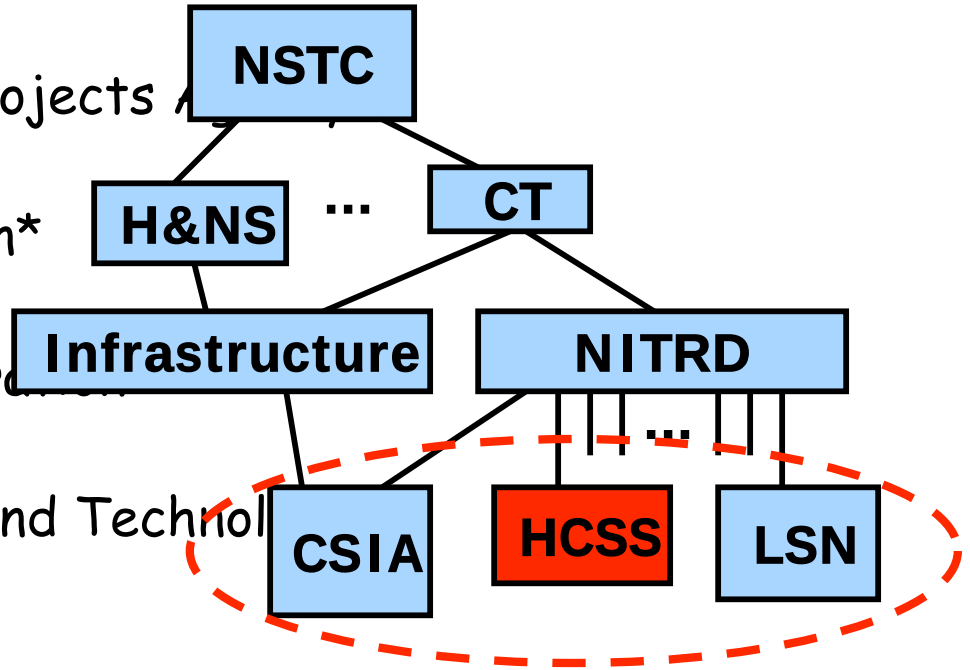
- For example: Google+IBM and NSF
  - Google+IBM providing software and services on large data cluster to academic community reached by NSF. Why?
    - NSF's broad reach: all US academic institutions, all sciences and engineering
    - NSF's merit review process and infrastructure
- Other companies welcome!
- Other models of engagement welcome!

Where are We Now:

NITRD
NSF
US

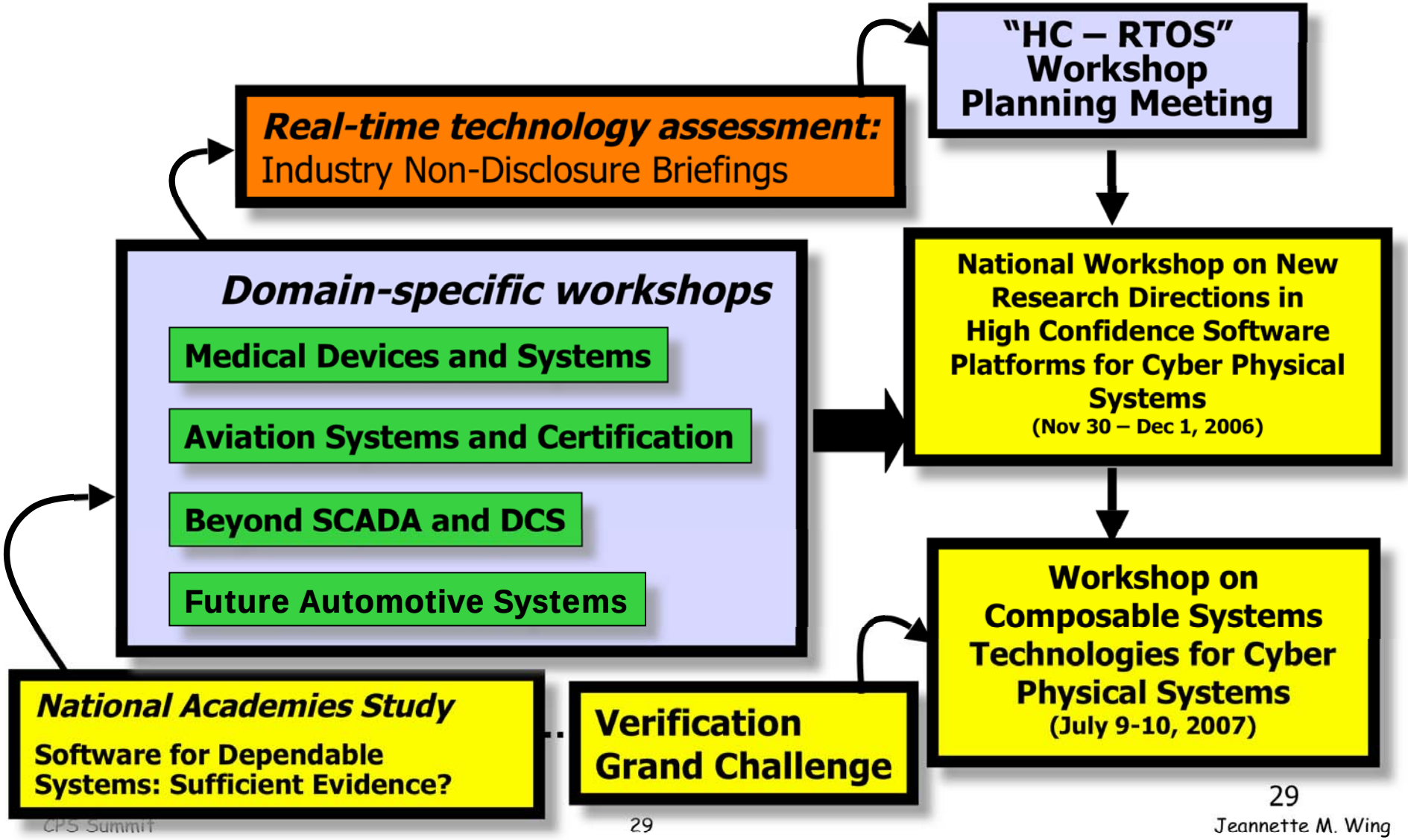
NITRD: High-Confidence Software and Systems (HCSS) Agencies, 2008

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



* Cooperating agencies

NITRD/HCSS Activities towards R&D Needs Assessment



Research Needs Assessment – Resources

Domain-specific workshops

- 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/
  - Joint Workshop On High Confidence Medical Devices, Software, and Systems (HCMDSS) and Medical Device Plug-and-Play (MD PnP) Interoperability, Boston, MA, June 25-27, 2007, http://rtg.cis.upenn.edu/hcmdss07/index.php3
- National Workshop on Aviation Software Systems: Design for Certifiably Dependable Systems, (HCSS-AS) (NSF, AFRL, NASA, FAA)
  - Planning Workshop, Seattle, WA, November 9-10, 2005, http://chess.eecs.berkeley.edu/hcssas/previousMeetings.html
  - National R&D Road-Mapping Workshop, Alexandria, Virginia, October 5-6, 2006, http://chess.eecs.berkeley.edu/hcssas/index.html
- High Confidence Critical Infrastructures: "Beyond SCADA: Networked Embedded Control Systems" (NSF, NIST, NSA)
  - US Planning Workshop, Washington, DC, March 14-15, 2006, http://www.truststc.org/scada/march06_plan.html
  - US National R&D Road-Mapping Workshop, Pittsburgh, Pennsylvania, November 8-9, 2006, http://www.truststc.org/scada/
- High Confidence Automotive Cyber-Physical Systems
  - Planning meeting: RTSS, Tucson, December 3, 2007
  - National meeting: April 3-4, 2008, Troy, MI, http://varma.ece.cmu.edu/auto-cps/

Research Needs Assessment, cont'd.

- "New Research Directions in Composition and Systems Technology for High Confidence Cyber-Physical Systems" – July 9-10, 2007, Arlington, VA, draft report, http://ike.ece.cmu.edu/twiki/bin/view/CpsReports/WebHome

- National Academies study: "Sufficient Evidence? Design for Certifiably Dependable Systems," http://www7.nationalacademies.org/cstb/project_dependable.html
  - 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
- Real Time GENI Workshop, Reston, VA, February 6-7, 2006, http://www.geni.net/GDD/GDD-06-32.pdf
- Open Verification Initiative
  - Response to Hoare Verification Grand Challenge: Open verification technology for industrial-strength system and software analysis and composition, VSTTE 2005, Zurich, Switzerland, http://qpq.csl.sri.com/vsr/vsi.pdf, http://qpq.csl.sri.com/vsr/manifesto.pdf

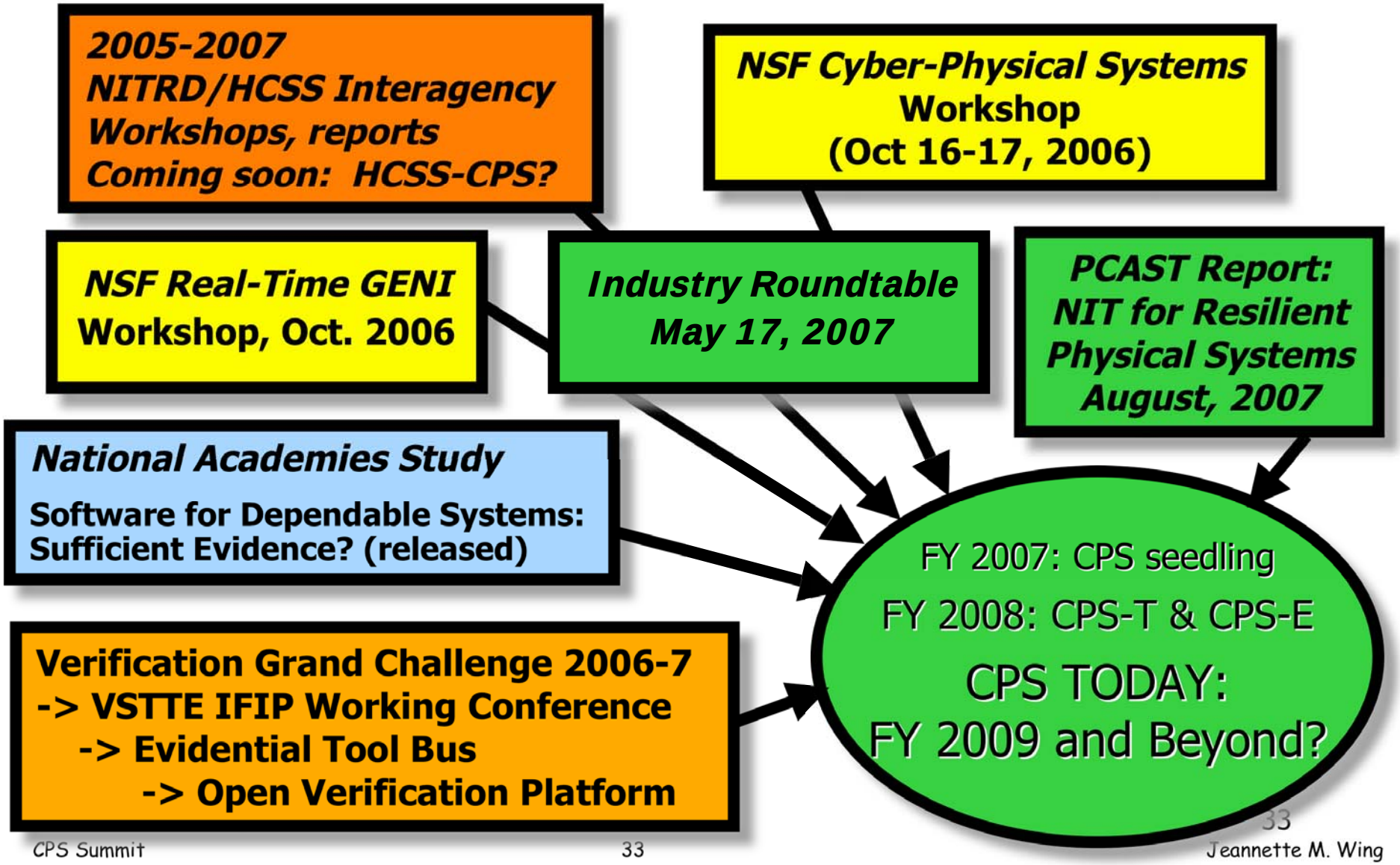
Upcoming HCSS Actions

- 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



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

- CPSWeek 2008 IEEE/ACM: RTAS 2008, HSCC 2008, IPSN 2008, http://www.cpsweek.org/
- CPS Funding Opportunities
  - FY 2007, exploratory CSR theme, NSF 07-504
  - FY 2008, expanded CSR exploration, NSF 08-538, http://www.nsf.gov/pubs/2008/nsf08538/nsf08538.htm
    - 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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