Science of Design for Societal-Scale Cyber- Physical Systems

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Collaborators

- ## Vanderbilt University
  Professors David Hess (co-PI), Gabor Karsai, Xenofon Koutsoukos, Himanshu Neema, Janos Sztipanovits (PI), Dan Work

- ## UC Berkeley
  Professors Shankar Sastry (UCB PI), Claire Tomlin

- ## University of Oldenburg
  Professors Werner Damm (U. Oldenburg PI), Jurgen Niehaus

- ## TU Munich
  Professor Alexander Pretschner (TUM PI)

A New Industrial Revolution Is Unfolding

Motivation (2017): *Societal discourse in architecting and constraining the new generations of H-CPS is necessary*

- **New AI/ML technologies** and **Industrial Platforms** (IoT, Fog Computing, Industrial Internet) inspired huge interest in and **enabled the development** of Societal-Scale Cyber-Physical Systems (SSCPS).
- **Industrial competition** increasingly drive development and **societal needs accelerate adoption** of this system category

Examples are:

- Transportation networks: **Connected and Autonomous Vehicles**
- 3D urban transportation: **Personal Air Mobility and Package Delivery**
- Energy distribution networks: **Smart Grid, Transactive Energy**

Viewpoint
Ethics of Technology Needs More Political Philosophy

Incorporating considerations of reasonable pluralism, individual agency, and legitimate authority.

AS A DRIVER, have you ever asked yourself whether to make left turns? Unprotected left turns, that is, left turns with oncoming traffic, are among the most difficult and dangerous driving maneuvers. Although the risk of each individual left turn is negligible, if you are designing the behavior of a large fleet of self-driving cars, small individual risks add up to a significant number of expected injuries in the aggregate. Whether a fleet of cars should make left turns is a question that any developer of self-driving cars and any designer of mapping and routing applications faces today.

A more general issue is at stake here: the decision of whether to make left turns involves a trade-off between safety and mobility (the time it takes to get to a destination). You gain safety at the expense of mobility by driving around the block and thereby avoiding left turns. But you gain mobility at the expense of safety by designing self-driving cars to zip through small gaps in oncoming traffic. Other situations that exemplify this mobility—safety trade-offs
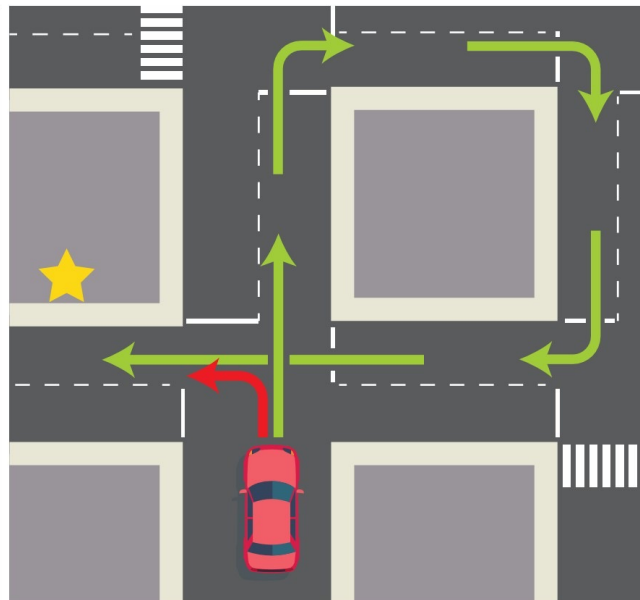
centrally via software as cars become increasingly automated.

driving cars typically focuses on two approaches to answering such ques-

Johannes Himmelreich
Communications of ACM
Vol 63 No. 1

Tradeoff between mobility and safety
 What is the right balance for self-driving cars?

Should the decisions based on
- moral theory (individual autonomy)?
- social science (using empirical data)?

Author convincingly argues to use political philosophy

– reasonable pluralism - **opinions may differ**
– respect for human agency - **individual autonomy**
– legitimate autonomy – **decision authority**

We cannot expect that the accepted position for self-driving cars will be universal: social context matters

Two sides of the coin:

- Adjusting public policy to new technology …but convergence cannot be expected across different countries..

- **Create technology that can be parameterized by societal context**

Project Goals

- **Understand** and **compare** the nature, scope, and evolution of **policies** and **societal expectations** in the operation of societal-scale H-CPS in the US and in Europe

- Investigate **methods for** the explicit and formal **representation of societal context** (operational, privacy, safety, security policies, incentives, pricing and market policies) that are machine interpretable and impact the structure and behavior of H-CPS

- Develop **policy-aware architectures** that guarantee the enforcement of policy requirements during the operation of a new generation of H-CPS.

Project Structure
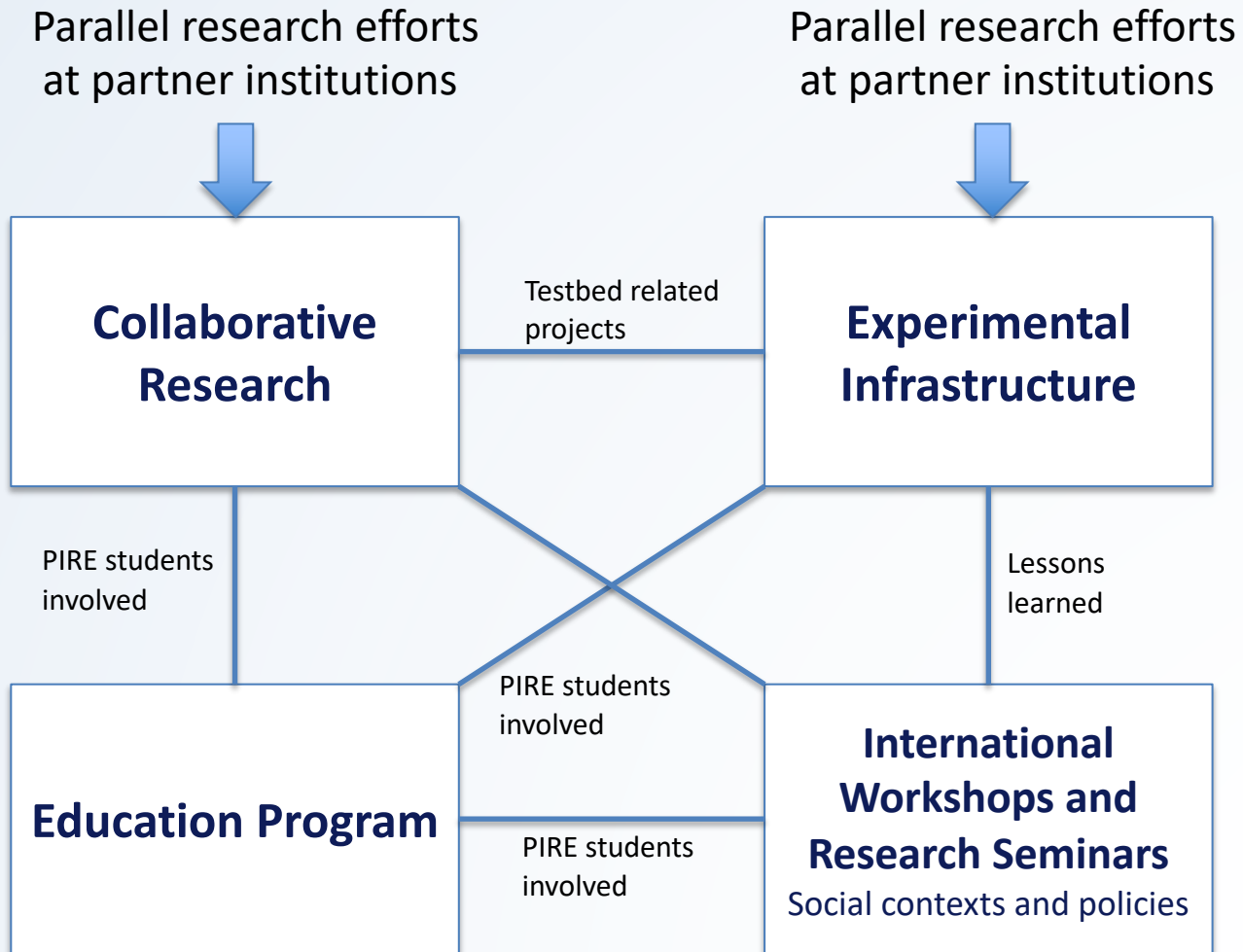
Collaborative Research Highlights

- Annual identification of research topics

- Organizing PIRE student involvement
  (e.g. summer internship –on-site or virtual)
  Used also in student recruitment

- Joint research and publications
  - See Research Talks:

    Hess & Lee: Bringing Societal Perspective Into
    Multidisciplinary Design Thinking and Practice

  - Pretschner & Karsai: Joining Models of Human
    Behavior and Technical Systems

  - Work & Pretschner: Living Laboratories and Experiments for Connected Vehicles
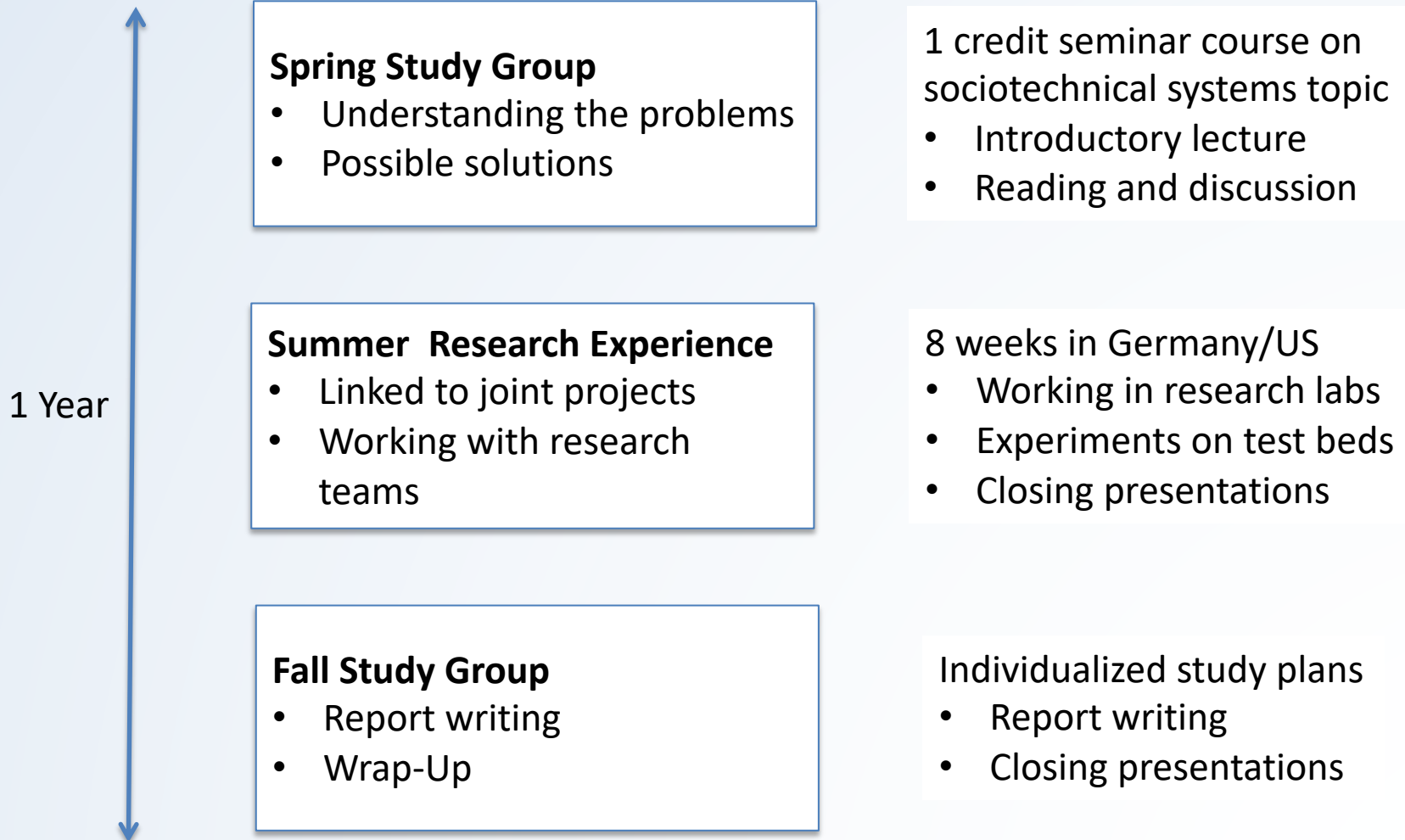
Selected collaborative efforts for FY2020

- Simulation integration platforms for Transactive Energy (TE) Studies (Sebastion Lehnhoff (Oldenburg), Janos Sztipanovits, David Hess and Himanshu Neema (Vanderbilt)
- Causality based assurance case modeling using Goal Structured Notation and other assurance case modeling variants
  Alexander Pretschner (TU Munich) and Gabor Karsai (Vanderbilt)
- Simulation-based study of traffic flow dynamics with mixed autonomy vehicles
  Werner Damm and Jochem Rieger (Oldenburg), Andreas Luedtke (OFFIS), Frank Koester (DLR), Dan Work (Vanderbilt)
- Delay differential equation for string stability
  Dan Work (Vanderbilt) and Alexander Pretschner
- Accountability for UAVs
  Alex Pretschner (TU Munich) and Claire Tomlin (UC Berkeley)
- Modeling human behavior in interaction spaces
  Claire Tomlin (UC Berkeley), Andreas Luedtke, Jochem Rieger and Werner Damm (Oldenburg)
- Provable confidence level in perception chain with learning enabled components
  Claire Tomlin (UC Berkeley), Xenofon Koutsoukos (Vanderbilt), Martin Fränzle (Oldenburg), Harald Ruess (fortiss), and Werner Damm (Oldenburg)
- Social acceptability of autonomous systems
  David Hess (Vanderbilt), Werner Damm, Janika Mattes and Markus Tepe (Oldenburg), Alexander Pretschner (TU Munich)
- Justification Logics
  Alexander Pretschner (TU Munich), Martin Fränzle and Werner Damm (Oldenburg)

Experimental Infrastructure

- Identified areas:

  - Living Labs for Connected and Autonomous Vehicles (in Munich and Nashville)
    See Research talk:
    Drs. D. Work (VU) and A. Pretschner (TUB): Living Laboratories and Experiments for Connected Vehicles

  - Simulation Testbeds for Transactive Energy (Vanderbilt and U. Oldenburg)

    Drs. H. Neema (VU) and S. Lehnhoff)Oldenburg) Comparative analysis of the Mosaic and CPSWT and integration concepts.

Undergraduate Education

1 Year

Spring Study Group
- Understanding the problems
- Possible solutions

1 credit seminar course on sociotechnical systems topic
- Introductory lecture
- Reading and discussion

Summer Research Experience
- Linked to joint projects
- Working with research teams

8 weeks in Germany/US
- Working in research labs
- Experiments on test beds
- Closing presentations

Fall Study Group
- Report writing
- Wrap-Up

Individualized study plans
- Report writing
- Closing presentations

Our program has been accepted as part of IMMERSION VANDERBILT
a campus-wide initiative for undergraduate education

International Workshops and Research Seminars

- Societal and Technological Research Challenges for Highly Automated Road Transportation Systems in Germany and the US: Diversities and Synergy Potentials - Washington D.C. 30/31 October 2018
  - 50 participants from leading US and German research organizations and regulatory authorities
  - Report completed

- Workshop on Assured CPS Autonomy for 3D Urban Transportation: Drones, Flying Cars, and Beyond - Virtual Meeting, June 9-10, 2021,
  - 34 participants from US and German research organizations and industry
  - Report is under preparation

- Preparation is ongoing for the Workshop on Acceptance of Smart Energy Systems (June 22)

- Invited presentations from TUM and U. Oldenburg at Summer Internship program and at the Spring Seminar
(available on project web site)

Workshop Report

Societal and Technological Research Challenges for Highly Automated Road Transportation Systems in Germany and the US

Diversities and Synergy Potentials

Washington D.C. 30/31 October 2018
Organized by the NSF-/DFG-PIRE project "SD-SSCPS" (Science and Design of Societal Scale CPS)

Workshop hosted by DLR and organized by German Aerospace Center (DLR), SafeTRANS, Vanderbilt University, University of California at Berkeley

Steering Committee: Karsten Lemmer, Werner Damm, Janos Stzipanovits, Shankar Sastry, Claire Tomlin, Frank Köster, Meike Jipp

Operational Organizing Team: Henning Mosebach, Werner Damm, Frank Köster, Jürgen Niehaus, Janos Stzipanovits, Florian Plötzwich

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In progress

Team Interactions and Management

- Monthly Executive Committee meetings coordinated by Katie Dey, research project manager
  - Annual list of collaborative project candidates
  - Tracking status of collaborations and joint papers
  - Student internship coordination
  - Workshop organization

- Personal collaborations in conjunction with diverse research efforts at universities

- Talks at research seminars and meetings

- Joint papers and reports

Impact of Pandemic

- Our international summer internship program had to be cancelled in 2020/2021 and reorganized in virtual format due to travel ban to and from German
  - For the 2020 and 2021 student cohorts cancelling the travel to Germany was a clear loss. Trying remote internship with mentors in Germany was welcomed by students this summer and proved to be a viable approach.

- Last minute cancellation of our fully organized US-Germany Workshop on Assured CPS Autonomy for 3d Urban Transportation: Drones, Flying Cars and Beyond. The workshop was planned for March 5-6, 2020 at UC Berkeley. The workshop finally was run in virtual format in June, 2021
  - The tangible loss is over one year delay, but the rescheduled workshop was successful.

- Progress and expenditures slowed down. The two years break in international internship opportunity and in mutual face-to-face meetings slowed our momentum, but the virtual format we experimented with has shown promise (even advantage in some issues).

Summary

- Our international team is working well and the research is producing results documented in papers and workshop reports

- Our project is timely: significance of social context rapidly increases and becoming a major concern in the design of societal-scale systems

- The research area has strong appeal for our students

- The pandemic had negative impact on gaining international experience and active engagement for our students, but new forms of student mentoring help

- Strong interest among partners for follow-on and spin-off efforts