Enabling Applied Research and Technology Transfer with Models
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My Main Points

▸ Use-driven research is interesting, challenging and measurably valuable
▸ Funding realities are changing; clearer value demanded
▸ Examples of use-driven research (*models help*)
The Fraunhofer-Gesellschaft

- Europe’s largest application-oriented research organization
- Geared to research that meets society’s many needs: health, mobility, energy, communications, security, production, etc.
Joseph von Fraunhofer (1787 – 1826)

- Researcher - Discovered “Fraunhofer lines” in the solar spectrum
- Inventor - Developed new methods for processing lenses
- Entrepreneur - Director of a glassworks
mp3 – A Fraunhofer Invention

- 1994: Fraunhofer IIS and Micronas jointly develop the first one-chip mp3 decoder.
  - Fraunhofer IIS also creates the first prototype mp3 player
- 1995: Fraunhofer and Thomson introduce a joint licensing pool for mp3-related software and patterns
- Today: mp3 and its successors in use in over 7 billion devices worldwide
The Fraunhofer-Gesellschaft at a Glance

The Fraunhofer-Gesellschaft undertakes applied research of direct utility to private and public enterprise and of wide benefit to society.

Nearly 25,000 staff

More than 70% is derived from contracts with industry and from publicly financed research projects.

Almost 30% is contributed by the German federal and State Governments.

69 institutes and research units

Total volume €2.1 billion

2016

Global HQ in Germany

Major infrastructure capital expenditure and defense research

More than 70% is derived from contracts with industry and from publicly financed research projects.
The Fraunhofer Model

- Fraunhofer’s funding model is designed to keep research centers engaged with industry
- Ideally, annual center revenues should have the following makeup:
  - 1/3 Institutional (base) funding
  - 1/3 Competitive public sector funding
  - 1/3 Industry contracts
Fraunhofer USA locations

- San Jose, CA
- East Lansing, MI
- Plymouth, MI
- Brookline, MA
- Boston, MA
- College Park, MD
- Newark, DE
- Storrs, CT

- Fraunhofer USA Headquarters
- Centers
- Office
Our Vision

- Accelerating economic and industrial development for its customers by using innovative model-based methods for developing and assuring complex software-intensive systems.
Modeling and Simulation

- System modeling
- Simulation
- Model-based testing
SW Design and Development

- Requirements definition
- Architectural design
- Agile development and continuous testing
Safety and Security

▸ Threat modeling
▸ Secure coding
▸ Security requirements
Project Mgmt. / Analytics

- Risk Assessment
- Regulatory Compliance
- Project Management
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Graduate Study at UCI

- Great environment / collaborators
- Ample funding
- Field was relatively new and expanding rapidly
Curiosity-Driven Research

- Free to investigate broadly, without must concern for practice
The Good and Bad

- Graduate study was a great learning experience
- Wasn’t pushed to consider potential impact
Moving to UMD

- Began to create my research program
- Began to see value in striving for greater impact
- Built a partnership with AT&T Bell Laboratories
AT&T Bell Labs

- Software Production Research Department (SPRD) was intentionally located near one of AT&T’s key development sites in Naperville, IL
- Created to support 5ESS digital switch development
- 5ESS - Flagship product for AT&T
  - ~20 MLOC
  - Massively configurable, supporting over 50 patch lines
  - Extreme reliability requirements
  - Engineering staff exceeded 5k FTE
Openness and Impact

▷ Department collaborated with many academic partners
▷ Looking for the “Twin-Win”
  ▷ Basic research advancements
  ▷ Solutions to practical problems
<table>
<thead>
<tr>
<th>Quest for Practical Use?</th>
<th>No</th>
<th>Yes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quest for Fundamental Understanding?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>Pure Basic Research (Bohr)</td>
<td>Use-Driven Basic and Applied Research (Pasteur)</td>
</tr>
<tr>
<td>No</td>
<td>Pure Applied Research (Edison)</td>
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Staffing Focused on Three Fundamental Capabilities

▸ Empirical data
▸ Data visualization
▸ Algorithms/Formal methods
Empirical Data

- Key tool for understanding problems, tracking progress towards a solution, and quantifying the solution’s value

- Twin Win
  - Research: The Code Decay Project
  - Practice: Analysis methods for evaluating new tools
Data Visualization

▶ Need ways to explore and make sense of data

▶ Twin Win
  ▶ Research: SeeSoft widely cited
  ▶ Practice: SeeSoft eventually the basis for a spin-off company
Algorithms/Formal Methods

▸ Embodies automatable technical insight

▸ Twin Win
  ▷ Research: Verisoft model checker
  ▷ Practice: Used Verisoft to analyze and improve CDMA call-processing software
SPRD’s Success in Pasteur’s Quadrant

▸ SPRD merged innovative, validated theory with practical solutions

▸ A truly unique and successful research environment
  ▹ Publishing highly influential research
  ▹ Developing, applying and commercializing research output
  ▹ Developing researchers who continue to have substantial success in academic and industrial positions
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- Use-driven research is interesting, challenging and measurably valuable
- **Funding realities are changing; clearer value demanded**
- Examples of use-driven research (**models help**)
Linear Model of Innovation:

- Invention - Basic Research by Universities
- Innovation - Applied Research by Labs and Research Centers
- Diffusion - Development by Industrial Companies
Federal R&D Expenditures as a Share of US Budget at Lowest Point in 60 Years

Source: SSTI; AAAS Analysis of Historical Budgets
Federal Funding is Flat to Decreasing in Several Agencies That Traditionally Fund CS and Engineering

Basic Research Accounts for Less Than 1/5th of Total US R&D Spending

Source: National Science Board’s Science and Engineering Indicators 2014
Industry is the Largest Source of US R&D Funding

Basic Research is not Industry’s Top Priority
The Decline of Basic Research in Corporate R&D

- *Killing the Golden Goose? The Decline of Science in Corporate R&D*, Ashish Arora, Sharon Belenzon, and Andrea Patacconi
- Basic research share of private R & D has fallen significantly
- Competitive pressures are pushing firms to:
  - Narrow their scope and outsource non-core functions, including research and development
  - Place greater emphasis on the “D” in R&D and favor incremental innovation
  - Rely more on research-intensive organizations and startups (and indirectly Universities) for innovation
The Business of Research is Changing

- Traditional sources of basic research funding are shrinking
- Industry funds are being directed to more applied areas with shorter payback times
- Portfolio view of funding streams is helpful
- Industry companies are more open to partnerships than ever
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▸ Examples of use-driven research (models help)
“Adam, I have 200 researchers on contract around the world. I don’t need another research hobby. I need a solution.”

Corporate Executive
Large Medical Device Company
Eye Opening Quote #2

“Want to help someone? Shut up and listen!”

Ernesto Sirolli
Some Useful Strategies

▸ Be a servant
▸ Build teams to solve broad problems
▸ Leverage models for support cross-domain work and communication
▸ Create something reusable in each project: ideas, tools and services
Automatically Learning Specifications

- Automotive engineering company wanted to develop their model-driven engineering capabilities
  - Based on natural language specs with many implicit requirements
Automatically Learning Specifications

- Can we semi-automatically identify implicit / inconsistent requirements?

Diagram:
- Requirements
  - Transform to
  - System or Model
  - Infer Missing Reqs
  - System or Model
Automatically Learning Specifications

Models or Source Code of Automotive Devices

Automated Test Generation
Static Analysis
Data Mining

Invariants Describing System Behavior

\[ \text{brake = pressed} \implies \text{mode = inactive} \]
\[ \text{speed < 26 mph} \implies \text{mode = inactive} \]
Automatically Learning Specifications

Models or Source Code of Automotive Devices

Automated Test Generation
Static Analysis
Data Mining

Additional Test Generation to verify and refine inferred specifications

Invariants Describing System Behavior

- brake = pressed \( \rightarrow \) mode = inactive
- speed < 26 mph \( \rightarrow \) mode = inactive
- speed < 25 mph \( \rightarrow \) mode = inactive
Automatically Learning Specifications

- Analysis of Resulting Specifications
- Requirement #1: The brake shall always deactivate the cruise control.
  - brake = pressed -> mode = inactive
Automatically Learning Specifications

▸ Analysis of Resulting Specifications

▸ Requirement #1: The brake shall always deactivate the cruise control.
  ▷ brake = pressed -> mode = inactive

▸ Requirement #2: The cruise control shall be inactive whenever vehicle speed is less than 30 mph.
  ▷ speed < 25 mph -> mode = inactive
Automatically Learning Specifications

▶ Developed tool for inspecting learned specifications
  ▶ Filtering results
  ▶ Creating state machines
CyberCardia

- NSF Center initiative to advance the state-of-the-art in Cyber-Physical Systems (CPS)
  - Developing novel verification techniques for CPS
  - Developing realistic heart models that can be used with in-the-loop testing of medical devices
- Goal: Reduce the need for trials involving humans and animals
CyberCardia: Our Contribution

▸ Specification learning of Medical Devices and Heart Models
  ▸ e.g. Analyze requirements for a blood infusion pump
  ▸ **Requirement Ex.:** If blood pressure is low and pulseOx value is good, then resume infusion and clear the warning alarm
    ▸ bloodPressure = good -> warning = 0
    ▸ bloodPressure = good & criticalStop = 0 -> infusion = 1
    ▸ bloodPressure = good & reset = 1 -> infusion = 1
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MBE Beyond Simulink, UML/SYSML

- Work with automotive manufacturer who uses component-level Simulink-style functional models
- Systems continually getting larger and more complex
  - Needs models of multiple system aspects
  - Wants to analyze dependencies across models
- Example: Advanced Driver Assistance Systems (ADAS) in modern cars provide certain functionality, but must meet functional and non-functional safety goals and standards
MBE - Agile Realization Approach

- Concept
- Ontology
- Meta-model
- Syntax, semantics
- Evaluation (tool supported)

- Profiling
- Modeling support
- Usability
- Analysis

Formalization
Integrated Safety Engineering

- Goal: Integrate architecture and safety artifacts
- Benefit: traceability, maintainability, automation, simulation
Analysis Example

- Opens up new possibilities for automated quality analysis

**Completeness Check**
- Requirements vs. Failure modes

**Qualitative and Quantitative Fault Tree analysis**
- Minimal Cut Sets
- Event probability
Implementation System

Profiles

C# Add-ins

ENTERPRISE ARCHITECT:
- No need to re-invent the wheel
- Fast prototyping
- Product definition is harder

-safeTbox-

Modeling Tool

- SysML integration
- Component Fault Trees
- Hazard and Risk Assessment
- Safety Concepts
- …

SafeTbox - Enterprise Architect extension
Useful Strategies

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Augmenting Test Suites Using Models

- Many engineering companies are beginning to transition to using model-driven approaches
  - They can’t make the switch overnight
  - Considerable assets exist supporting the status quo
NASA GMSEC

- Publish/Subscribe middleware used to interconnect space system components
- Had some existing test cases, but very incomplete coverage of requirements
public static void main( String args[] ) { 
    Status result = new Status();
    Connection conn = new Connection();
    ConnectionConfig cfg = new ConnectionConfig( args );

    // Create the connection
    result = ConnectionFactory.Create( cfg, conn );
    checkError( false, result, "Creating the connection object" );

    // Disconnect
    result = conn.Disconnect();
    checkError( true, result, "Disconnecting before connection is established" );

    // Connect
    result = conn.Connect();
    checkError( false, result, "Establishing the connection to the middleware" );
} //..main()
GMSEC Top-Level Testcase Model
Generating Test Cases from Test Model

- Tester specifies test case criteria
  - e.g. requirements coverage
- Tester specifies test suite criteria
  - e.g. 1,000 test cases
- Model Walker traverses model
  - A test case is a traversal from start node
  - Continues until stopping criteria met
  - Outputs executable test cases
New Test Cases Add High Value at Low Cost

- The new tests found many defects not found by the original test cases
- The new test cases were based only on information latent in the original test cases, yet covered many more combinations of nominal and off-nominal behavior
Generating Test Cases from Generated Test Models

Model Under Test (MBSE)

Model for Test Case Generation (MBT)

Reqs
Test Cases

SWalk

Generated
Test Cases

void readSensors()
{
    getAmbientAirTemperature ();
    getFuelRate ();
    getCoolantTemperature ();
    getThermoStatus ();
}
Supporting Porting to AUTOSAR Platform

- Major heavy vehicle manufacturer is changing OS platforms

Our plan
- Generate test model(s) from existing application test cases
- Generate new abstract test cases from test model
- Iteratively execute and refine test cases against original OS
- Based on performance, coverage and learned specifications
- Execute vetted test cases against AUTOSAR application
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Identifying Biological Threats
Project Team

- Designing, building, validating computational methods for identifying biological threats

- Large project team combining expertise in biology, bioinformatics and software and systems engineering
  - Fraunhofer supporting architectural design, agile development and validation
Models of DNA sequences
Some Useful Strategies

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✓ Create something reusable in each project: ideas, tools and services
Conclusions

▸ Use-driven research is interesting, challenging and measurably valuable
  ▷ Don’t artificially limit yourself to one kind of research style
▸ Funding realities are changing; clearer value demanded
  ▷ Don’t be an ostrich!
▸ You can do use-driven research
  ▷ Listen to customers, solve their problems, build teams, use models
Questions?

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