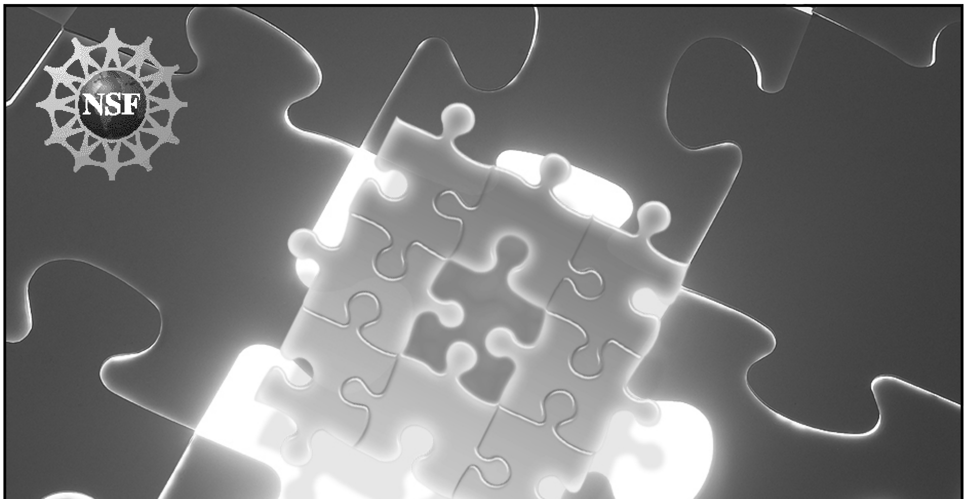

Design Science in Information Systems Research

Alan R. Hevner – University of South Florida
and the National Science Foundation

NSF Disclaimer

- Any opinion, findings, and conclusions or recommendations expressed in this material are those of the author and do not necessarily reflect the views of the National Science Foundation.

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Outline

- Introduction and Research Background
- The Design Science Research Paradigm
- Design Science Research Guidelines
- Case Study of Design Science Research
- Challenges
- Future Directions
- Science of Design Program at NSF
- Discussion

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Speaker Introduction

- Professor of Information Systems in the College of Business at the University of South Florida
- Ph.D. in Computer Science from Purdue University
  - Database Systems
- Taught at Univ. of Minnesota (CS) and Univ. of Maryland (IS)
  - Software Engineering with Harlan Mills at IBM
- Assignment at NSF for next two years
  - Science of Design Program
  - New Vision of Software Research

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Research Portfolio

- Design Science as a Research Paradigm
- National Institute for Applied Computational Intelligence (NIACI)
  - Computational Intelligence (CI) Testing Tools
  - Graduate Courses on Software Testing and Information Systems Security
- Next Generation Software Engineering Program
  - SEI IRAD Funding for Program Comprehension via Function Extraction
  - Flow-Service-Quality Framework for NGSE
  - HICSS 2007 Minitrack
- Control in Flexible Software Development
- Software Development Project Estimation
  - Information Markets
  - Extend COCOMO II Models
- Technology Transfer – PSP Case Study with SEI Cooperation
- Collaborative Programming and Agile Methods
- Telemedicine Quality Attributes – VA Partner
- Inspection Techniques for Graphical Software Development Models

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Design Science Research

- Sciences of the Artificial, 3rd Ed. – Simon 1996
  - A Problem Solving Paradigm
  - The Creation of Innovative Artifacts to Solve Real Problems
- Design in Other Fields – Long Histories
  - Engineering, Architecture, Art
  - Role of Creativity in Design
- Design Science in Information Systems
  - How to Perform Research in Design Science !
  - Formal Design Science Research Theories ?

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MISQ 2004 Research Essay

- A. Hevner, S. March, J. Park, and S. Ram, "Design Science Research in Information Systems," *Management Information Systems Quarterly*, Vol. 28, No. 1, March 2004, pp. 75-105.
- Historically, the IS field has been confused about the role of 'technical' research.
- Technical researchers felt out of the mainstream of ICIS/MISQ community.
  - Formation of Workshop on Information Technology and Systems (WITS) in 1991
- Initial Discussions and Papers
  - Nunamaker et al. 1991 – Electronic GDSS
  - Walls, Widmeyer, and El Sawy 1992 – EIS Design Theory
  - March and Smith 1995 from WITS 1992 Keynote
  - Encouragement from IS Leaders such as Gordon Davis, Ron Weber, and Bob Zmud
- Allen Lee, EIC of MISQ, invited authors to submit essay on Design Science Research in 1998
  - Four Review Cycles with multiple reviewers
  - Published in 2004
  - Selected in October 2005 as ISI Fast Breaking Paper

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IS Research Framework

- Information Systems (IS) are complex, artificial, and purposefully designed.
- IS are composed of people, structures, technologies, and work systems.
- Two Basic IS Research Paradigms
  - Behavioral Science – Goal is Truth
  - Design Science – Goal is Utility

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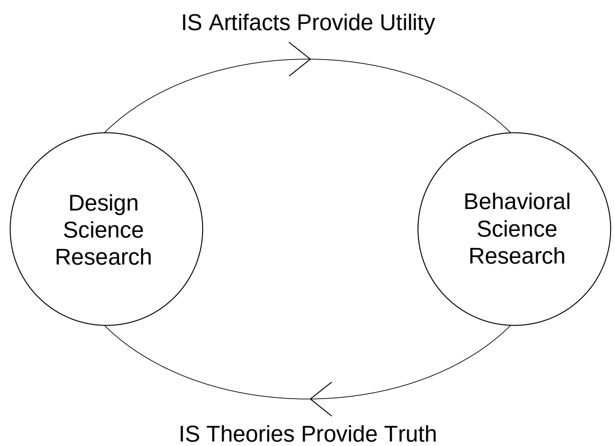
IS Research Cycle



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Design Science

- Design is a Artifact (Noun)
  - Constructs
  - Models
  - Methods
  - Instantiations
- Design is a Process (Verb)
  - Build
  - Evaluate
- Design is a Wicked Problem
  - Unstable Requirements and Constraints
  - Complex Interactions among Subcomponents of Problem and resulting Subcomponents of Solution
  - Inherent Flexibility to Change Artifacts and Processes
  - Dependence on Human Cognitive Abilities - Creativity
  - Dependence on Human Social Abilities - Teamwork

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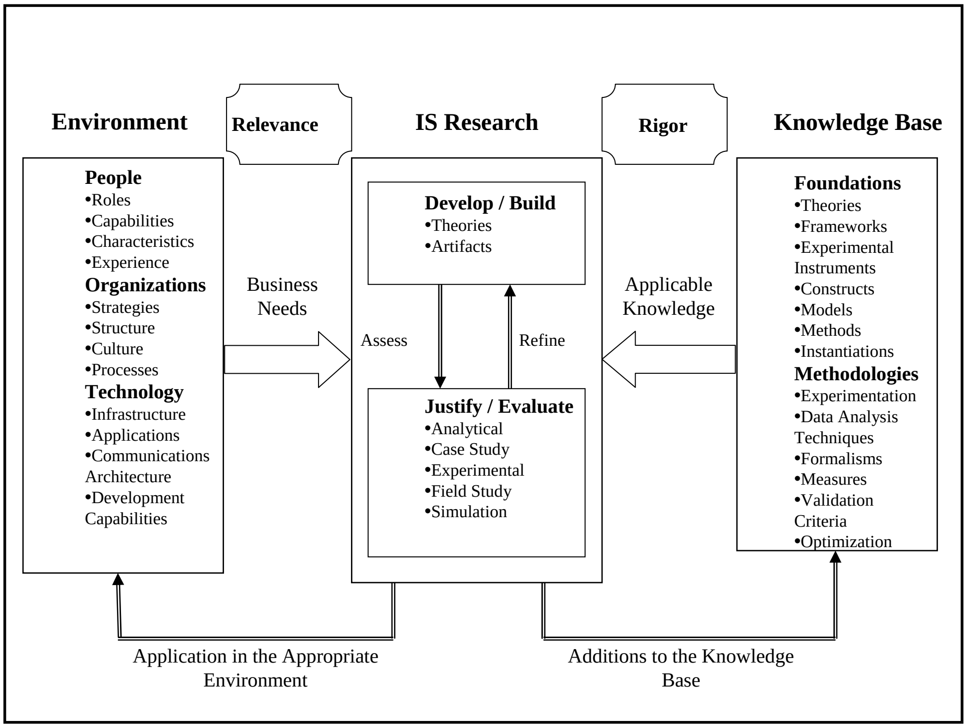

Guidelines for DS Research in IS

- Purpose of Seven Guidelines is to Assist Researchers, Reviewers, Editors, and Readers to Understand and Evaluate Effective Design Science Research in IS.
- Researchers will use their creative skill and judgment to determine when, where, and how to apply the guidelines to projects.
- All Guidelines should be addressed in the Research.

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Design Science Guidelines

Guideline	Description
Guideline 1: Design as an Artifact	Design-science research must produce a viable artifact in the form of a construct, a model, a method, or an instantiation.
Guideline 2: Problem Relevance	The objective of design-science research is to develop technology-based solutions to important and relevant business problems.
Guideline 3: Design Evaluation	The utility, quality, and efficacy of a design artifact must be rigorously demonstrated via well-executed evaluation methods.
Guideline 4: Research Contributions	Effective design-science research must provide clear and verifiable contributions in the areas of the design artifact, design foundations, and/or design methodologies.
Guideline 5: Research Rigor	Design-science research relies upon the application of rigorous methods in both the construction and evaluation of the design artifact.
Guideline 6: Design as a Search Process	The search for an effective artifact requires utilizing available means to reach desired ends while satisfying laws in the problem environment.
Guideline 7: Communication of Research	Design-science research must be presented effectively both to technology-oriented as well as management-oriented audiences.

Design as an Artifact

- The IT Artifact is the ‘core subject matter’ of the IS field.
- Artifacts are innovations that define the ideas, practices, technical capabilities, and products through which the analysis, design, implementation, and use of IS can be accomplished.
- Design Science Research in IS must produce an Artifact
  - Construct, Model, Method, Instantiation
- Research Design vs. Routine Design
  - Innovation vs. Use of Known Techniques

Problem Relevance

- Research Motivation
- The Problem must be real and interesting.
- Problem solving is a search process using actions to reduce or eliminate the differences between the current state and a goal state [Simon 1999].
- Design Science Artifact must be relevant and useful to IS practitioners - Utility.

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Design Evaluation

- Rigorous Evaluation of the Utility, Quality, and Beauty (i.e., Style) of the Design Artifact.
- Evaluation provides feedback to the Construction phase for improving the artifact.
- Design Evaluation Methods

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Design Evaluation Methods

1. Observational	Case Study – Study artifact in depth in business environment
	Field Study – Monitor use of artifact in multiple projects
2. Analytical	Static Analysis – Examine structure of artifact for static qualities (e.g., complexity)
	Architecture Analysis – Study fit of artifact into technical IS architecture
	Optimization – Demonstrate inherent optimal properties of artifact or provide optimality bounds on artifact behavior
	Dynamic Analysis – Study artifact in use for dynamic qualities (e.g., performance)
3. Experimental	Controlled Experiment – Study artifact in controlled environment for qualities (e.g., usability)
	Simulation – Execute artifact with artificial data
4. Testing	Functional (Black Box) Testing – Execute artifact interfaces to discover failures and identify defects
	Structural (White Box) Testing – Perform coverage testing of some metric (e.g., execution paths) in the artifact implementation
5. Descriptive	Informed Argument – Use information from the knowledge base (e.g., relevant research) to build a convincing argument for the artifact's utility
	Scenarios – Construct detailed scenarios around the artifact to demonstrate its utility

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Research Contributions

- What is New and Interesting?
- Does the Research make a clear contribution to the business environment, addressing a relevant problem?
- The Design Artifact
  - Exercising the artifact in the problem domain adds value to the IS practice
- Foundations
  - Extend and improve foundations in the design science knowledge base
- Methodologies
  - Creative development and use of methods and metrics

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Research Rigor

- Use of Rigorous Research techniques in both the Build and Evaluate phases
- Building an Artifact relies on mathematical foundations to describe the specified and constructed artifact.
  - Principles of Abstraction and Hierarchical Decomposition to deal with Complexity
- Evaluating an Artifact requires effective use of techniques in previous slide.
- Research must be both Relevant and Rigorous

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Design as a Search Process

- Good design is based on iterative, heuristic search strategies.
  - Simon's Generate/Test Cycle
  - Problem Simplification and Decomposition
  - Modeling Means, Ends, and Laws of the Problem Environment
- The Search for Optimal Solutions may not be feasible or tractable.
- The Search for Satisfactory Solutions may be the best we can do - Satisficing

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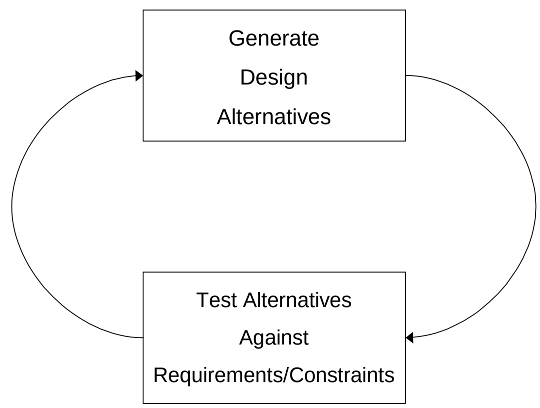
The Generate/Test Cycle



Communication of Research

- Technical audiences need sufficient detail to construct and effectively use the artifact.
  - How do I build and use the artifact to solve the problem?
- Managerial audiences need an understanding of the importance of the problem and the novelty and utility of the artifact.
  - Should I commit the resources (staff, budget, facilities) to adopt the artifact as a solution to the problem?
- Research presentation must be fitted to the appropriate audience (e.g., journal).

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Design Science Case Studies

- Three Exemplars in MISQ Paper
  - Gavish and Gerdes DSS 1998
  - Aalst and Kumar ISR 2003
  - Markus, Majchrzak, and Gasser MISQ 2002
- Presentation Example of a Recent Doctoral Dissertation Proposal
  - Monica Tremblay - Uncertainty in the Information Supply Chain: Integrating Multiple Health Care Data Sources

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Problem Relevance

- Problem Statement:
  Public policy knowledge workers draw on a set of pre-existing tools when acquiring data from multiple data sources available from the information supply chain. The data acquisition process and the task of correctly combining and manipulating data from multiple data sources in the information supply chain have many challenges: data are unbounded, data definitions and schemas vary, and there is no guarantee of data quality. In most cases, knowledge workers make decisions with available information and use "gut instinct" or experience to choose the correct course of action when data sources conflict or do not match expectations. These challenges are made even more complicated by the knowledge worker's own judgment biases. Existing tools can aid knowledge workers, yet the lack of integration among these tools aggravate cognitive and behavioral biases and result in missed opportunities for knowledge creation.

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Research Questions

- Can we design an effective Agent-Based IS (ABIS) that will automate the integration of multiple data sources with varying degrees of data quality in the IS supply chain to better support public policy decision makers?
- Can we evaluate the utility, quality, and efficacy of the Agent-Based IS?

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Research Rigor

- Design of the ABIS will be grounded by:
  - Data Products Foundations [Shankaranarayan et al. 2003]
  - Data Quality Foundations [Wang et al. 1997]
  - Behavioral Decision-Making Foundations [Tversky and Kahneman 1982]
- Design Evaluation of ABIS will be performed in two phases:
  - Field Study of Public Health Decision-Makers
  - Controlled Experiment

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Design as a Search Process

- Two Research Cycle Iterations
- Cycle 1:
  - Initial ABIS Design and Instantiation
  - Evaluation in Field Study with Feedback
- Cycle 2:
  - Improved ABIS Design and Instantiation
  - Evaluation in Controlled Experiment to Study Impacts on Behavioral Biases

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Design as an Artifact

- The Artifact is the Instantiation of an Agent-Based Information System (ABIS) for the integration and control of multiple data products. The ABIS will support Decision-Making in Public Health Policy.
- The ABIS will provide:
  - New Algorithms for Calculating Data Quality Metrics on Data Products
  - New Methods for Comparing and Integrating Data Products
  - New Human-Computer Interface Presentations to support Decision-Making

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Design Evaluation

- Cycle 1 – Field Study of How Public Health Policy workers use initial ABIS to support Decision-Making.
- Cycle 2 – Controlled Experiment on the use of the improved ABIS to study User Biases on Public Health Policy Decision-Making
  - Subjects will be graduate students in the College of Public Health
  - Task will be drawn from Field Study

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Research Contributions

- The Design Artifact
  - The ABIS will add clear value to Public Health Policy environments
- Foundations
  - New models and algorithms for calculating data quality metrics
  - New methods of integrating multiple data products
  - New methods of data product presentation to decision-makers

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Communication of Research

- Presentation of Research Results in top-quality IS journals and conferences
- Initial study that motivated this project:
  - Tremblay, Fuller, Berndt, and Studnicki, "Doing More with More Information: Changing Healthcare Planning with OLAP Tools," *Decision Support Systems*, In Press, Available on DSS Elsevier Website, 2006.

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Design Science Observations

- Design Science is Proactive with respect to technology (creating utility), Behavioral Science is Reactive (understanding truth)
  - We need both for an IS Research Cycle
- Align IS Design Science Research with real-world experience in Business and Industry
- Distinguish Design Science Research Artifacts from Routine System Building

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Design Science Challenges

- Inadequate Theory Base for Scientific and Engineering discipline
  - Science of Design Program at NSF
- Insufficient Sets of Constructs, Models, Methods, and Tools in Knowledge Base to Represent real-world Problems and Solutions
- Design is still a Craft relying on Intuition, Experience, and Trial-and-Error
- Design Science Research is perishable as technology advances rapidly
- Rigorous Evaluation Methods are difficult to apply in Design Science Research
- Communication of Design Science Results to Managers is Essential but a Major Challenge

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MISQ Paper Impacts

- Selected by ISI Essential Science Indicators for October 2005 as a Fast Breaking Paper in Economics & Business, Thomson-ISIR. Interview at http://www.esi-topics.com/fbp/2005/october05-AlanRHevner.html
- Google Scholar shows over 100 citations
  - Papers in MISQ, ISR, JMIS, JAIS
  - International impact
  - Doctoral Research

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Design Science Activities

- ICIS 2006 Design Science Track
  - 52 Papers submitted and 12 Accepted for Presentation
- MISQ Special Issue on Design Science Research, CFP – August 2006
- ECIS 2007 Keynote on Design Science
- Design Science Research Conference (DESRIST) – February 2006 and May 2007

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National Science Foundation

- Basic scientific research & research fundamental to the engineering process;
- Programs to strengthen scientific and engineering research potential;
- Science and engineering education programs at all levels and in all fields of science and engineering; and,
- A knowledge base for science and engineering appropriate for development of national and international policy

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NSF Strategic Mission

- **People:**
  to develop a diverse, internationally competitive and globally-engaged workforce of scientists, engineers, and well-prepared citizens
- **Ideas:**
  to provide a deep and broad fundamental science and engineering knowledge base
- **Tools:**
  to provide widely accessible, state-of-the-art science and engineering infrastructure
- **Organization Excellence:**
  to develop an agile, innovative organization that fulfills its mission through leadership in state-of the-art business practices

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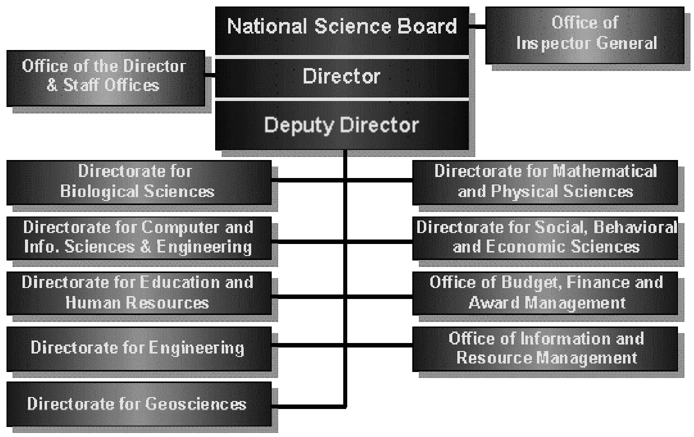
National Science Foundation



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CISE Mission

- CISE has three goals:
  - to enable the United States to remain competitive in computing, communications, and information science and engineering;
  - to promote understanding of the principles and uses of advanced computing, communications, and information systems in service to society; and
  - to contribute to universal, transparent, and affordable participation in an information-based society.

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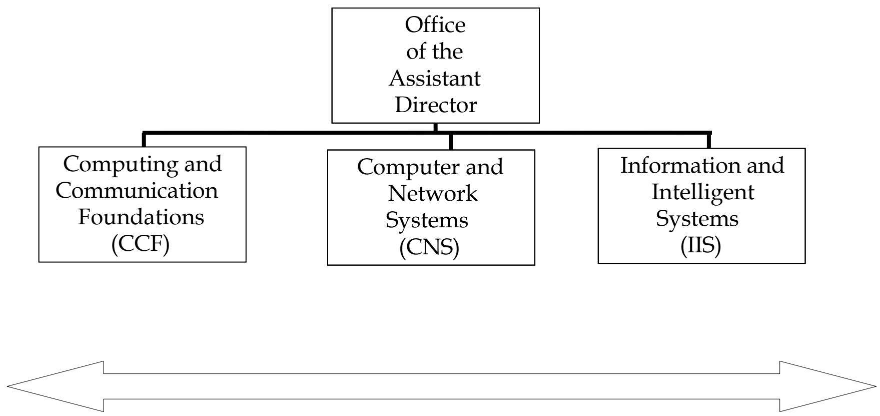
Current CISE Organization



Crosscutting Emphasis Areas

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Computing and Communication Foundations Division (CCF)

- Theoretical Foundations
  - Computer science theory; numerical computing; computational algebra and geometry; signal processing and communication
- Foundations of Computing Processes and Artifacts
  - Software engineering; software tools for HPC; programming languages; compilers; computer architecture; graphics and visualization
- Emerging Models and Technologies for Computation
  - Computational biology; quantum computing; nano-scale computing; biologically inspired computing

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Computer and Network Systems Division (CNS)

- Computer Systems
  - Distributed systems; embedded and hybrid systems; next-generation software; parallel systems
- Network Systems
  - Networking research broadly defined plus focus areas
- Computing Research Infrastructure
  - Equipment and infrastructure to advance computing research
- Education and Workforce
  - IT workforce; special projects; cross-directorate activities (e.g., REU sites, IGERT, ADVANCE)
- Proposal Deadline: January 17, 2007

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Information and Intelligent Systems Division (IIS)

- Systems in Context
  - Human computer interaction; educational technology; robotics; computer-supported cooperative work; digital government
- Data, Inference & Understanding
  - Databases; artificial intelligence; text, image, speech, and video analysis; information retrieval; knowledge systems
- Science & Engineering Informatics
  - Bioinformatics; geoinformatics; cognitive neuroscience; …
- Proposal Deadline: December 6, 2006

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CISE Cross-Cutting Emphasis Areas

- Characteristics
  - cut across clusters and divisions (and directorates)
  - address scientific or national priority
- FY 2007 Emphasis Areas
  - GENI: December 15, 2006
  - CPLAN: January 23, 2007
  - Science of Design: February 5, 2007
  - Creativity in IT: Solicitation in February

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Science of Design (SoD) Program at NSF

- Focus – Design of Software-Intensive Systems
- Advance design research and education to meet critical software design challenges
- New paradigms, concepts, approaches, models, methods, and theories to build an intellectual foundation for software design to improve the processes of constructing, evaluating, and modifying software-intensive systems
- Research must be intellectually rigorous, formalized where appropriate, supported by empirical evidence, open to creative expression, and teachable.

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SoD Program Objectives

- Fund original ideas on how to synthesize creative expression with scientific rigor in the design of relevant, useful software-intensive systems
- Import and adapt the most creative thinking about design from other scientific, engineering, and artistic fields while recognizing and addressing the unique nature of software
- Develop new, innovative constructs, models, methods, and tools to move software design into the next generation of complex, distributed computing environments.

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Science of Design Awards

- FY 2005 Competition
  - Proposals received in May 2004
  - Received ~ 190 proposals (~ 160 projects)
  - Made 16 Awards, Project success rate of ~10%
  - Approximately $10 Million invested
- FY 2006 Competition
  - Proposals received in January 2006
  - Received ~ 120 proposals (~ 90 projects)
  - Made 30 Awards, Project success rate of ~25%
    - Many awards were made as SGERs
  - Approximately $10 Million invested

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SoD 2007 Solicitation

- New Solicitation Posted Oct. 12, 2006
- Proposal Deadline: Feb. 5, 2007
- Web URL:
  http://nsf.gov/funding/pgm_summ.jsp?pims_id=12766&org=CISE&from=home
- Funding: $10 Million
- Focus on Interdisciplinary Team Projects
- Individual PI Proposals are encouraged
- Educational Proposals
- Demonstration Testbeds for SoD Results

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Discussion

- Future Directions of Design Science Research in IS
  - Foundations
  - New Applications
  - Changing Business Environments (People, Technologies, Strategies)
  - Interdisciplinary Research Teams
    - Industry – University Cooperative Projects
- Questions on NSF SoD Proposals

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