Design Science Research in Information Systems

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Outline

- What is Design Science
- A Framework for IS Research
- Guidelines for Design Science in Information Systems Research
- Applications of the Design Science Research Guidelines
- Challenges for Design Science Research

What is Design Science?

Behavior-science paradigm

- Roots in ***natural science*** research methods
- It seek to develop and justify theories
- These theories impact and impacted by design sciences

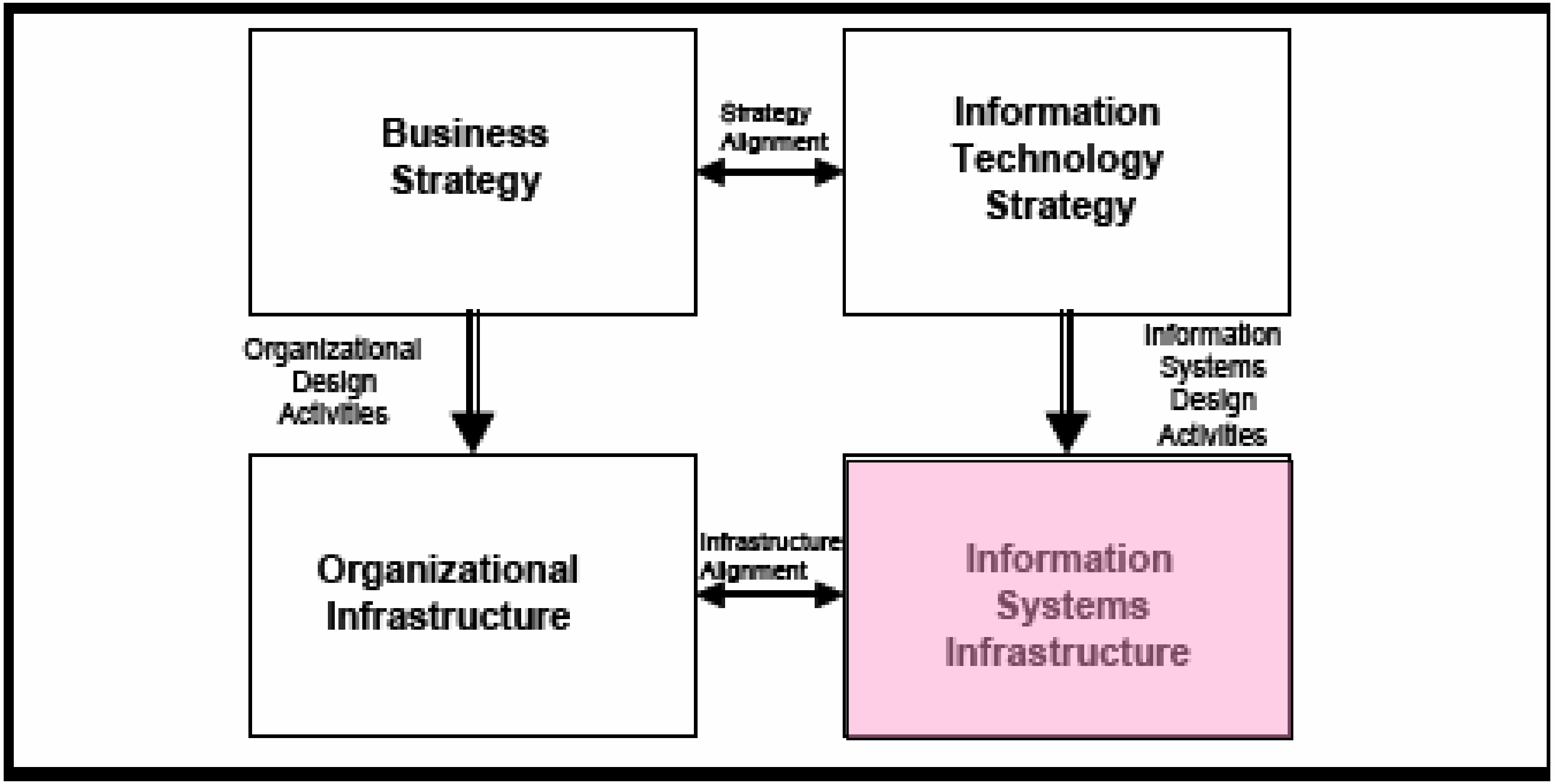
Design-science paradigm

- Roots in ***engineering and sciences*** of the artificial (Simon 1996)
- It seek to create innovations
- Their creation relies on existing Kernel theories
  - That are applied, tested, modified, and extended through the experience, creativity, intuition, and problem solving capabilities of the research

Two Sides of the Same Coin

- Technology and behavior are ***not dichotomous*** in an information system. They are inseparable.
- Behavior-science paradigm seeks to find "***what is true***"; whereas design-science paradigm seeks to create "***what is effective***"
- Truth (justified theory) and utility (artifacts that are effective) are two sides of the same coin.

A Framework for IS Research



- Design science will be limited to the activities of building the IS infrastructure within the business organization

Objective of Design Science Research

- Create and evaluate IT artifacts to solve the identified organizational problem
- Such artifacts are represented in a structured form, such as ***software***, ***formal logic***, and ***rigorous mathematics*** to ***informal natural language descriptions***

Design is both a process and a product

- This build-and-evaluated loop is typically ***iterated*** a number of times before the final design artifact is generated
- March and Smith(1995) identify ***two*** design phases and ***four*** design artifacts produced by the design process
  - Two design phases: build and evaluate
  - Four artifacts: constructs, models, methods, and instantiations

Two-step Loop in Design Phase

- ***Output* = *a set of activities* + *an artifact***
- **Design** process
  - A sequence expert activities that produces an innovative product
- **Evaluation** of the artifact
  - Provides feedback information and a better understanding of the problem in order to improve both the ***quality of the product*** and ***the design process***

Role of Evaluation in Design science

- A mathematical basis for design allows many types of ***quantitative evaluations*** of an IT artifact
  - Optimization proofs
  - Analytical simulation
  - Quantitative comparison with alternative designs
- Further evaluation of a new artifact
  - Empirical and qualitative methods

IT Artifacts (I)

- Constructs
  - Provide the language in which problems and solutions are defined and communicated
- Models
  - Use constructs to ***represent*** a real world situation – the design ***problem*** and its ***solution space***

IT Artifacts (II)

- Methods
  - Define processes
  - Provide guidance on how to solve problems

- Instantiations
  - Show that constructs, models, or methods can be implemented in a working system

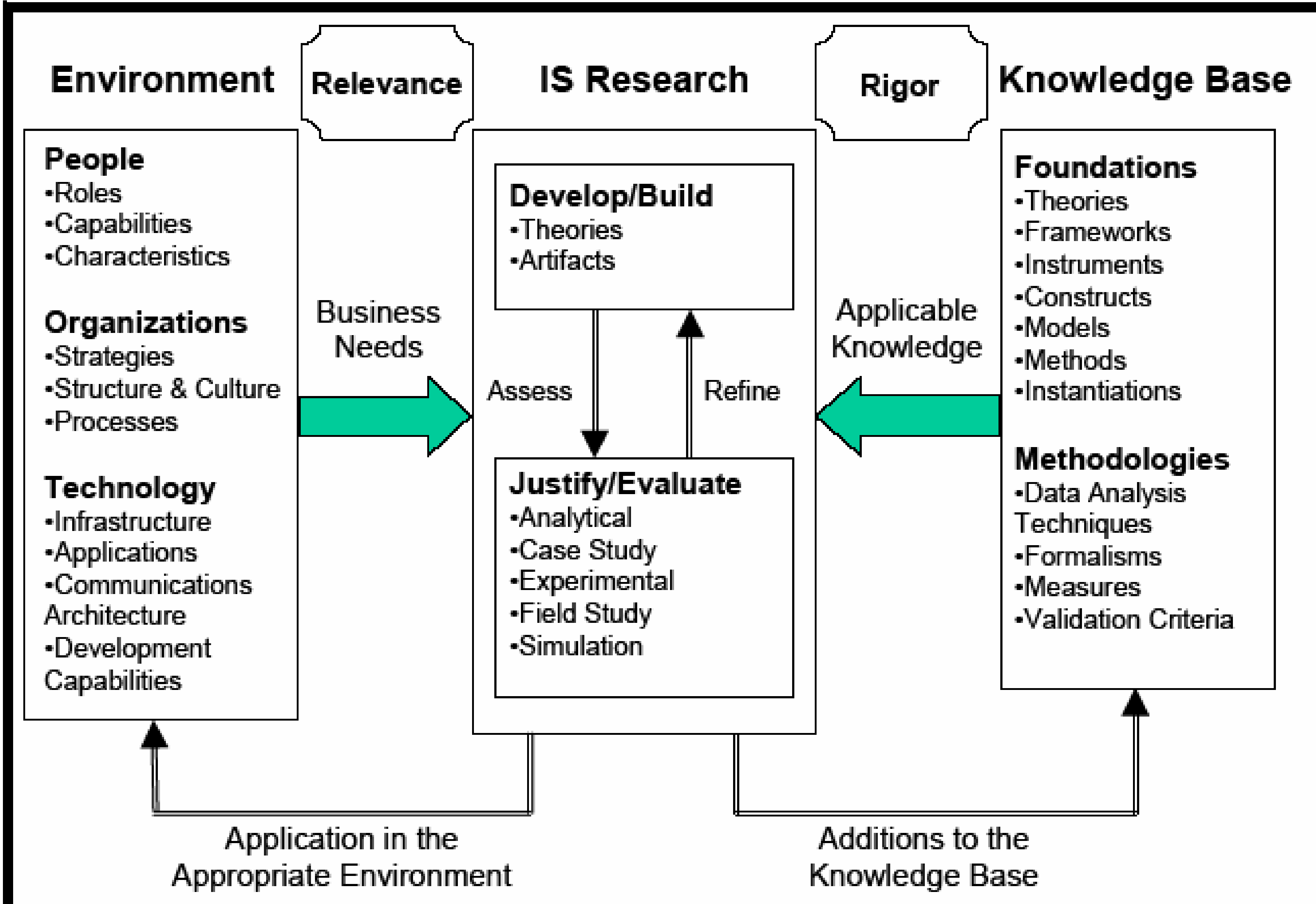


Figure 2. Information Systems Research Framework

Design-science vs. Routine design

- Design science research is different from routine design or system building in the nature of the problem and solutions.
- Routine design
  - is application of existing knowledge to organizational problems
  - Such as constructing a financial or marketing IS using best practice artifacts
- Design-science research
  - addresses important unsolved problems in unique or innovative ways or solved problems in more effective or efficient ways

Design Science Research Guidelines

Table 1. Design-Science Research 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.

Evaluation Methods

Table 2. 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

Sample Design Science Research

Three exemplar articles

- Gavish and Gerdes (1998), which develops techniques for implementing anonymity in Group Decision Support Systems environment
- Aalst and Kumar (2003), which proposes a design for an eXchangeable Routing Language(XRL) to support electronic commerce workflows among trading paterners
- Markus, Majchrzak, and Gasser (2002), which proposes a design theory for the development of information systems built to support emergent knowledge processes

A Composite Approach to Inducing Knowledge for Expert Systems Design

Author: Ting-Peng Liang

Source: Management Science, Vol. 38, No. 1, 1992.

Rule Induction Problem

- Quinlan's ID3 was the most popular method
  - Using entropy to measure the information content of each attribute
  - Deriving decision rules through a repetitive decomposition process

Major drawbacks of ID3 and Extension

- They process nominal and nonnominal variables in the same way
- The probability assessments are typically based on the frequency of occurrence in the training data set.
  - Fine when nominal attributes are involved but not suitable for nonnominal attributes.

Niche of the paper

- The goal of the paper to present a new approach , call a Composite Rule Induction System(CRIS), to overcome the problems.
- Features of the new approach
  - Assessing probabilities for rules
  - Applying different methods to handle different attributes
    - Nominal: cross-tabular approach
    - Nonnomial: statistical inference approach
  - Using a rule scheduling mechanism to determine the relative importance of the candidate.

Major Components of CRIS

- Three major components
  - A hypothesis generator
    - Determining hurdle values and the proper relationship between independent and dependent attributes
  - A probability calculator
    - Determining the probability associated with each rule
  - A rule scheduler
    - Determining how candidate rules should be organized to form a structure

Empirical Evaluation of CRIS

- Three experiments were conducted to evaluate the performance of CRIS.

- To compare four other method:
  - – Discriminant analysis(DA)
  - – ACLS algorithm(entropy-based)
  - – PLS1 algorithm (entropy-based)
  - – Backpropagation(BP)

Comparison of the Methods

Methods	MDA	Entropy-based	BP	CRIS
Selection criteria	Covariance matrix	Entropy	Delta rule	Rule saliency
Selection processes	Matrix operations	Repetitive decomposition	Simulation	Rule scheduling
Resulting models	Linear equations	Rule structure	Network structure	Rule structure

Empirical Evaluation of CRIS -Bankruptcy prediction

- 50 cases
- Four nominal and five attributes
- Randomly divided into training set and testing set.
- Five Methods
- Twelve Experiments conducted

Results of the first experiment

Method	Average accuracy
CRIS	0.808
ACLS	0.771*
PLS1	0.754**
DA	0.758**
BP	0.783

**significantly *10% significantly

Second: LIFO/FIFO Choice

- 58 pairs of training and testing data
- Two categories(28,30) by the industry type
  - affected by nominal/not affected

- Three different sample size was examined.
  - L/S:large size training /small size testing
  - M/M:medium size training/medium size testing
  - S/L:small size training /large size training
- Comparing CRIS and ACLS

Results of the second experiment

Empirical Results of the Second Experiment

	Industry-Dominated Sets				Nondominated Sets*				Global Average
	L/S	M/M	S/M	Mean	L/S	M/M	S/M	Mean	
ACLS	90.0	89.0	88.3	89.1	62.3	62.6	60.9	61.9	75.5%
CRIS	92.2	89.8	91.2	91.1	69.5	70.1	67.8	69.1	80.1%

*significant at 1% level F=22.8

Third:Simulation on Computer-Generated Data

- Three factors were controlled in the third experiment
- natural of domains
  - purely nominal,purely nonminal, and mixture of the two
- data distributions
  - normal and nonnormal
- attribute correlation
  - high and low

Results of the third experiment

TABLE 5

Average Predictive Accuracy in Various Settings

Distribution		Normal		Bimodal	
Correlation		High	Low	High	Low
Nonnominal	ACLS	0.875	0.94	0.825	0.865
	CRIS	0.925	0.95	0.835	0.845
	PLS1	0.84	0.81	0.722	0.715
Mixed	ACLS	0.855	0.915	0.79	0.835
	CRIS	0.91	0.96	0.83	0.87
	PLS1	0.849	0.881	0.76	0.844
Nominal	ACLS	0.815	0.945	0.725	0.78
	CRIS	0.84	0.96	0.82	0.85
	PLS1	0.85	0.96	0.833	0.86

Results of the third experiment

- CRIS performs well if the domain includes nonnominal attributes and correlation is high
- Predictive accuracy of CRIS is more stable than ACLS and PLSI
- Overall average accuracy:
  - ACLS 0.847
  - CRIS 0.883
  - PLS1 0.827

How the Sample meets the Guidelines (I)

- Problem Relevance
  - Knowledge acquisition (now often called data mining) is a difficult but important issue
- Research Rigor
  - Every step is supported by statistical theories and existing methods
- Design as a Search Process
  - Divide the rule induction process into three steps and design algorithms to solve the problem in each step.

How the Sample meets the Guidelines (2)

- Design as an Artifact
  - The result is an innovative method and can be implemented into a software.
- Design Evaluation
  - Three experiments were performed to compare with four existing competing methods
- Research Contributions
  - The new approach introduces new concepts and is proven to outperform existing methods
- Research Communication
  - Include technical description and managerial implications

Challenges

Danger of Design Science (I)

- There is an ***inadequate theoretical base*** upon which to build an engineering discipline of information systems design (Basili 1996)

- Many informal, descriptive IS models ***lack*** an underlying ***theory*** base

Danger of Design Science (2)

- The existing knowledge base is often ***insufficient*** for design purposes
  - designers must rely on intuition, experience, and trial-and-error methods
- Design-science research is ***perishable***
  - AI、OODB、Year 2000
- ***Rigorous*** evaluation methods are extremely ***difficult*** to apply in design-science research

Integrating the design-science and behavior-science Paradigms

- The design of an artifact, its formal specification, and an assessment of its utility, often by comparison with competing artifacts, are ***integral to design-science research***.
- These must be ***combined*** with ***behavioral and organizational theories*** to develop an understanding of business problems, contexts, solutions, and evaluation approaches adequate to servicing the IS research and practitioner communities.

Questions and Comments