Technische Universität München

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Complexity and Diversity Management of Application Landscapes

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Outline

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1. **Complexity and Diversity Management of Application Landscapes**

Motivation

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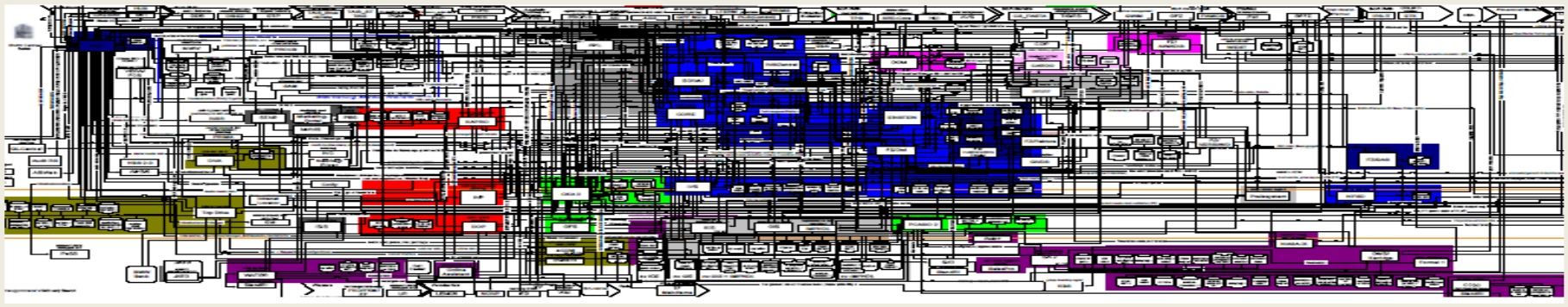
Business challenges

- Increasing uncertainty in the business environment → organizational agility
- Balance of exploration and exploitation → ambidexterity



IT challenges

- Uncontrolled growth of application landscapes → business silos
- Shrinking IT budgets → cost cutting in IT operations through standardization

Challenge: Manage diversity to decrease costs but enable innovation.

Motivation

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Exploration

Competitive Advantage

New Digital Options

AL Diversity (Diversification)

Ambidexterity

Exploitation

Cost savings

Economies of Scale

AL Diversity (Standardization)

Challenge: How to manage application landscape (AL) diversity to decrease costs but enable innovation and co-evolution with the environment?

Sambamurthy, Vallabh; Bharadwaj, Anandhi; Grover, Varun (2003): Shaping agility through digital options: Reconceptualizing the role of information technology in contemporary firms. In: MIS Quarterly 27 (2), pp. 237–263.

Theoretical foundation: The resource-based view

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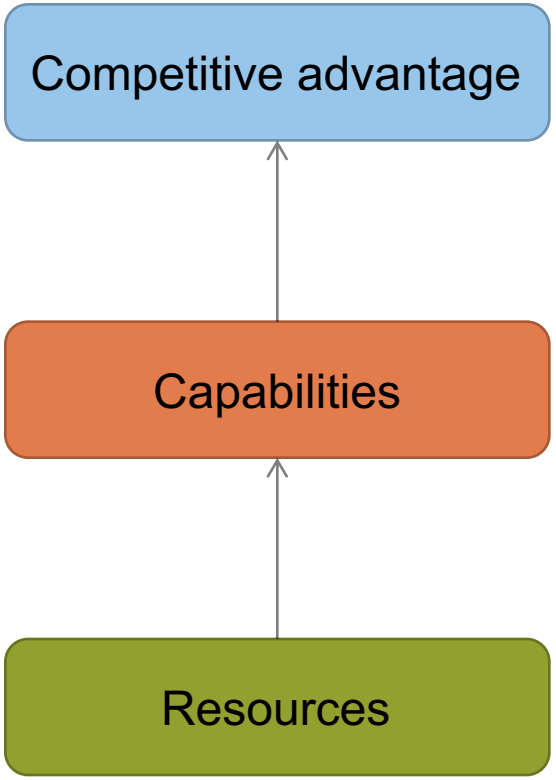

- Value-creating strategy
- Maintain a combination of resources that cannot be possessed or built up in a similar manner by competitors

- Information-based organizational processes
- Firm-specific
- Improve the productivity of resources

- Valuable
- Rare
- In-imitable
- Non-substitutable

Pfeffer, J.; Salancik, G. (1978), The external control of organizations : a resource dependence perspective; New York: Harper & Row
Barney, J.B., (1991), Firm Resources and Sustained Competitive Advantage. Journal of Management; 17, (1), pp.99–120.
Amit, R.; Schoemaker, P.J.H. (1993), Strategic assets and organizational rent. Strategic Management Journal; 14, (1), pp. 33–46.

Theoretical foundation: The value of digital options

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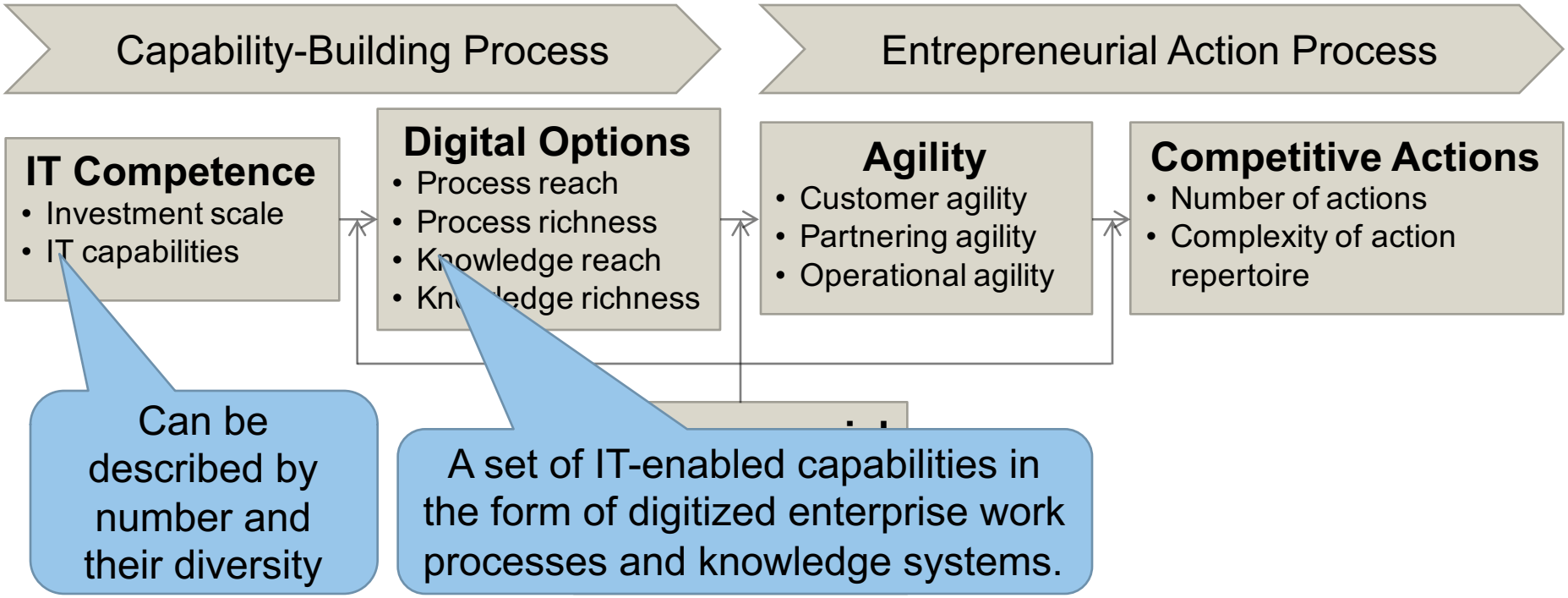
Resource-based view of the firm (Ferrier et al. 1999)

→ Firms that possess a more complex base of resources and capabilities will be in an advantageous position to launch competitive actions.

Capability-Building and Entrepreneurial Action (Sambamurthy et al. 2003)



Ferrier, W. J., Smith, K. G., and Grimm, C. M. (1999): The Role of Competitive Action in Market Share Erosion and Industry Dethronement: A Study of Industry Leaders and Challengers. In: Academy of Management Journal 42 (4), pp. 372-388.
Sambamurthy, Vallabh; Bharadwaj, Anandhi; Grover, Varun (2003): Shaping agility through digital options: Reconceptualizing the role of information technology in contemporary firms. In: MIS Quarterly 27 (2), pp. 237–263.

Goals

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Epistemic goal

Develop a deeper understanding of the concept diversity in the context of application landscapes.

1. *Conceptualization*: What aspects contribute to the diversity of AL?
2. *Perception in practice*: What benefits and drawbacks relate to AL diversity?

Design goal

Design metrics for supporting decisions regarding the diversity of application landscapes.

3. *Quantification*: What metrics quantify different aspects of diversity and which data is needed for their calculation?
4. *Software support*: How can diversity quantification be integrated in an EAM tool?
5. *Steering mechanisms*: How to influence AL diversity?

Becker, Jörg (1995): Strukturanalogien in Informationsmodellen. In: Wolfgang König (Hg.): Wirtschaftsinformatik '95: Physica-Verlag HD, S. 133-150.

Research process (design science)

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Problem Identification	Objective Definition	Design & Development	Demonstration	Evaluation
▪ Complexity Framework (*AMCIS 2014*) ▪ CALM Workshop I ▪ Diversity in Systems and AL (*CSD&M 2014*)	▪ CALM Workshop II ▪ Drivers & Consequences (*Zeitschrift für Controlling 2014*) ▪ Survey ▪ **Diversity Framework**	▪ **Novel Balance Metric** (*MKWI 2016*) ▪ **Novel Disparity Metric** ▪ System Dynamics Model (*WI 2015*) ▪ Prototypic implementation	▪ CALM Workshops III-V ▪ Empirical metric results (*HICCS 2015*)	▪ **4 Case Studies** ▪ Different Industry Sectors ▪ Different Company Size

Hevner, A.R.; March, S.T.; Park, J. and Ram, S.: Design science in information systems research. MIS Quarterly, 28(1):75–105, 2004.
Peffers, K.; Tuunanen, T.; Rothenberger, M.A. and Chatterjee, S.: A Design Science Research Methodology for Information Systems Research. Journal of Management Information Systems, 24(3):45–77, 2007.

Complexity of Application Landscapes

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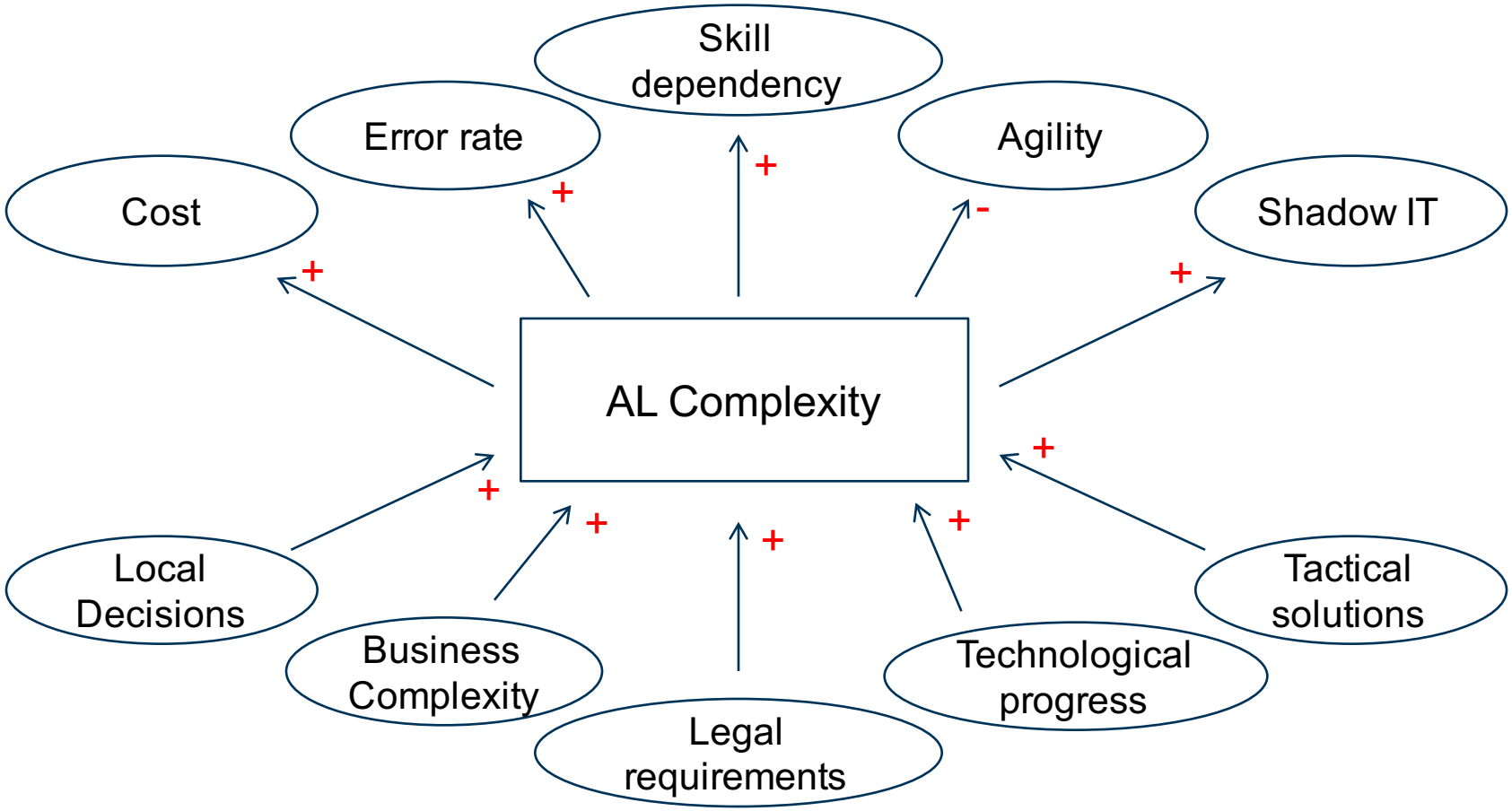
Focus group results



Schneider, Alexander W.; Matthes, Florian (2014): Unternehmensarchitekturgestütztes Controlling zur Beherrschung der IT-Komplexität. In: Zeitschrift für Controlling 26 (12), pp. 694–699.

Diversity of Application Landscapes

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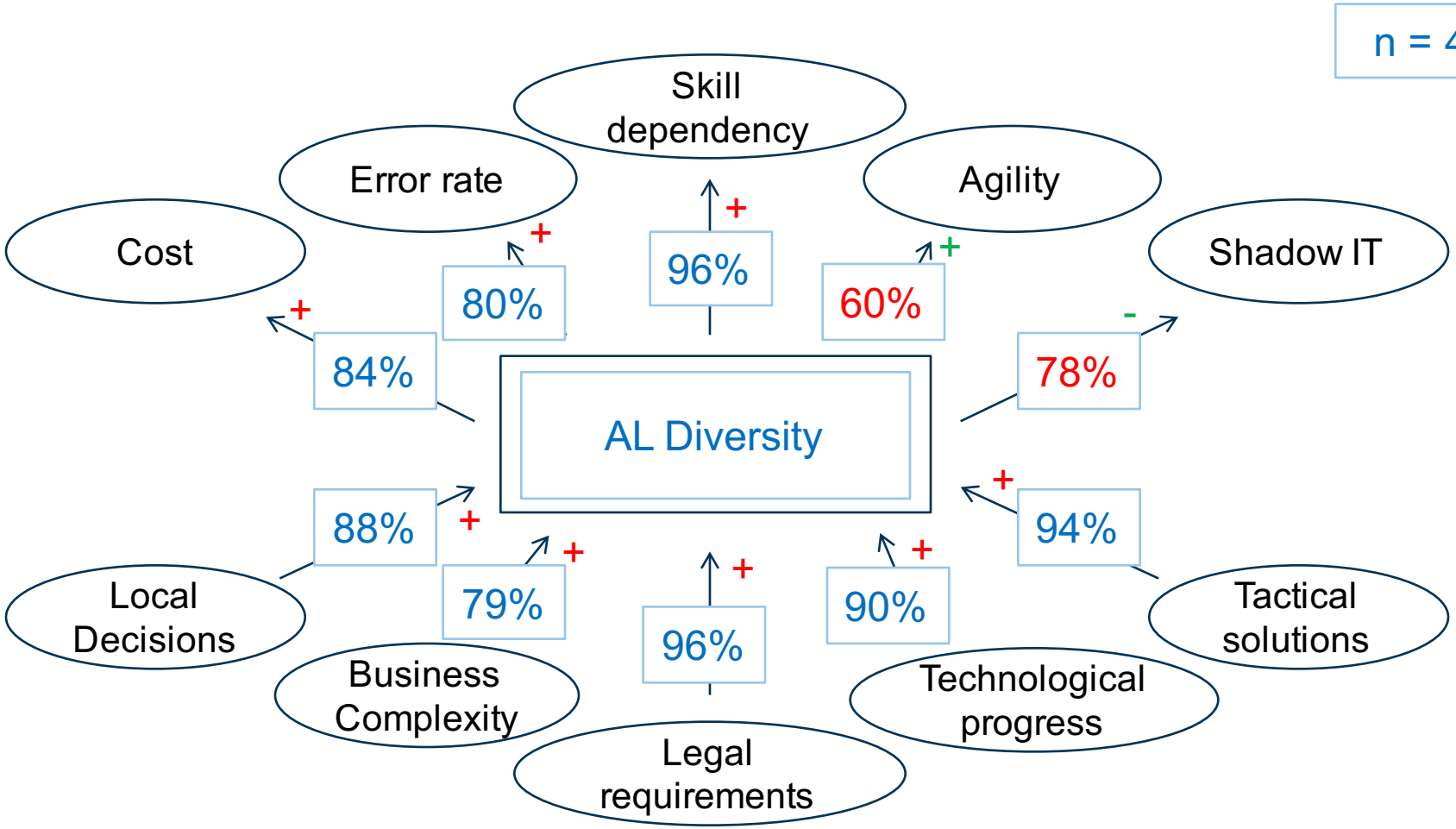

Diversity perception in practice

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n = 43

Why companies decrease their application landscape diversity

- Cost savings: 86% (only 12% measure cost savings)
- Preservation of manageability: 67%
- Implementation of security guidelines: 47%

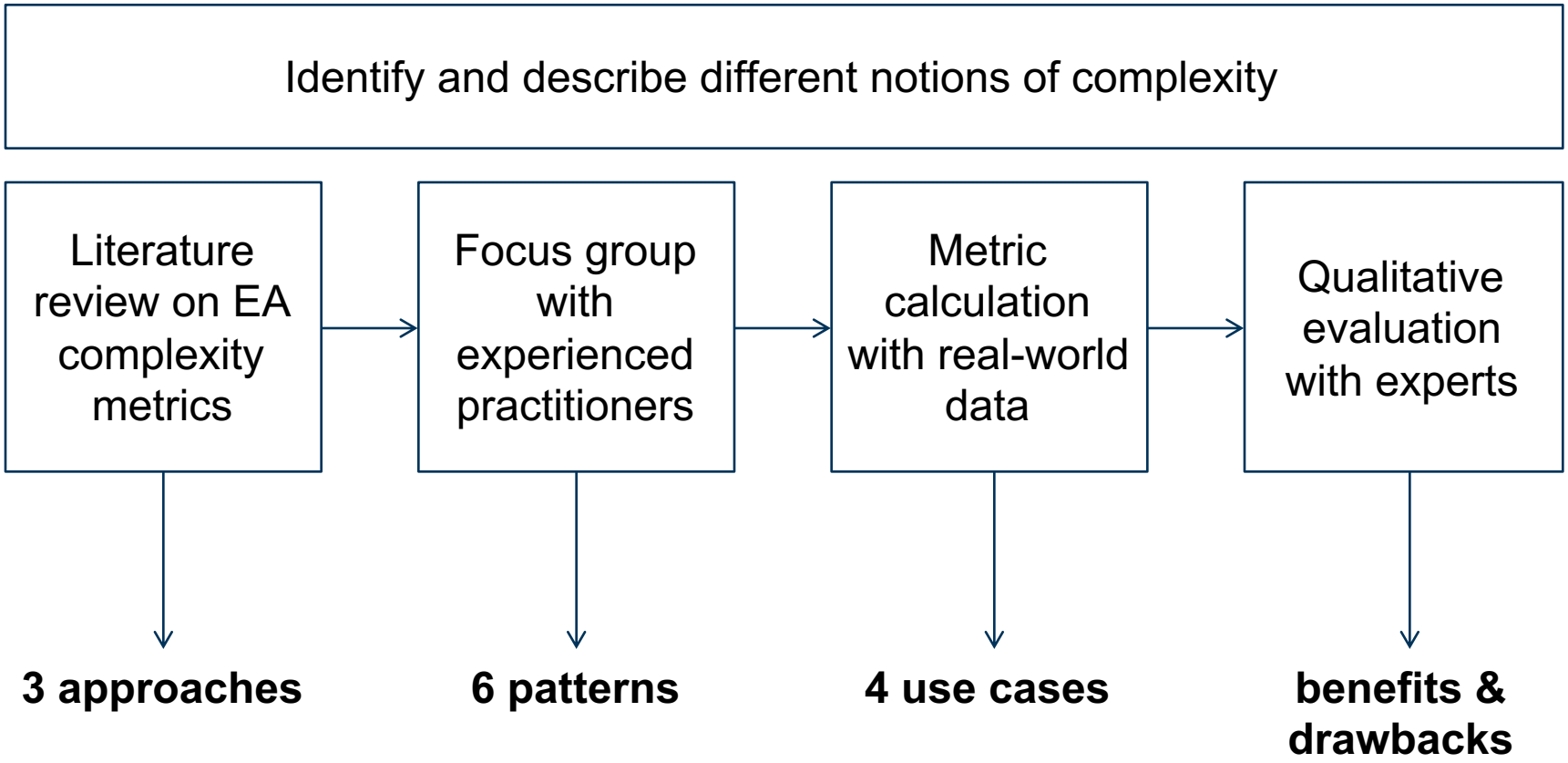
Preliminary results for diversity effects

- AL diversity increases costs for IT operations: 97%
- AL diversity decreases time-to-market of new products: 94%
- AL diversity decreases technology dependence: 83%
- AL diversity is required for innovation: 92%
- AL diversity enables better business solutions: 74%

How companies influence application landscape diversity

- Defining standard products for new developments: 86%
- Definition of technical platforms: 80%
- Concessions for non-standard products: 71%
- Actively increase diversity: 44% (Multi-product strategies and subcompanies)

Research Design



Schneider, Alexander W.; Reschenhofer, Thomas; Schuetz, Alexander; Matthes, Florian (2015): Empirical Results for Application Landscape Complexity. In: 48th Hawaii International Conference on System Sciences (HICSS). Kauai, HI, USA.

The Complexity Cube

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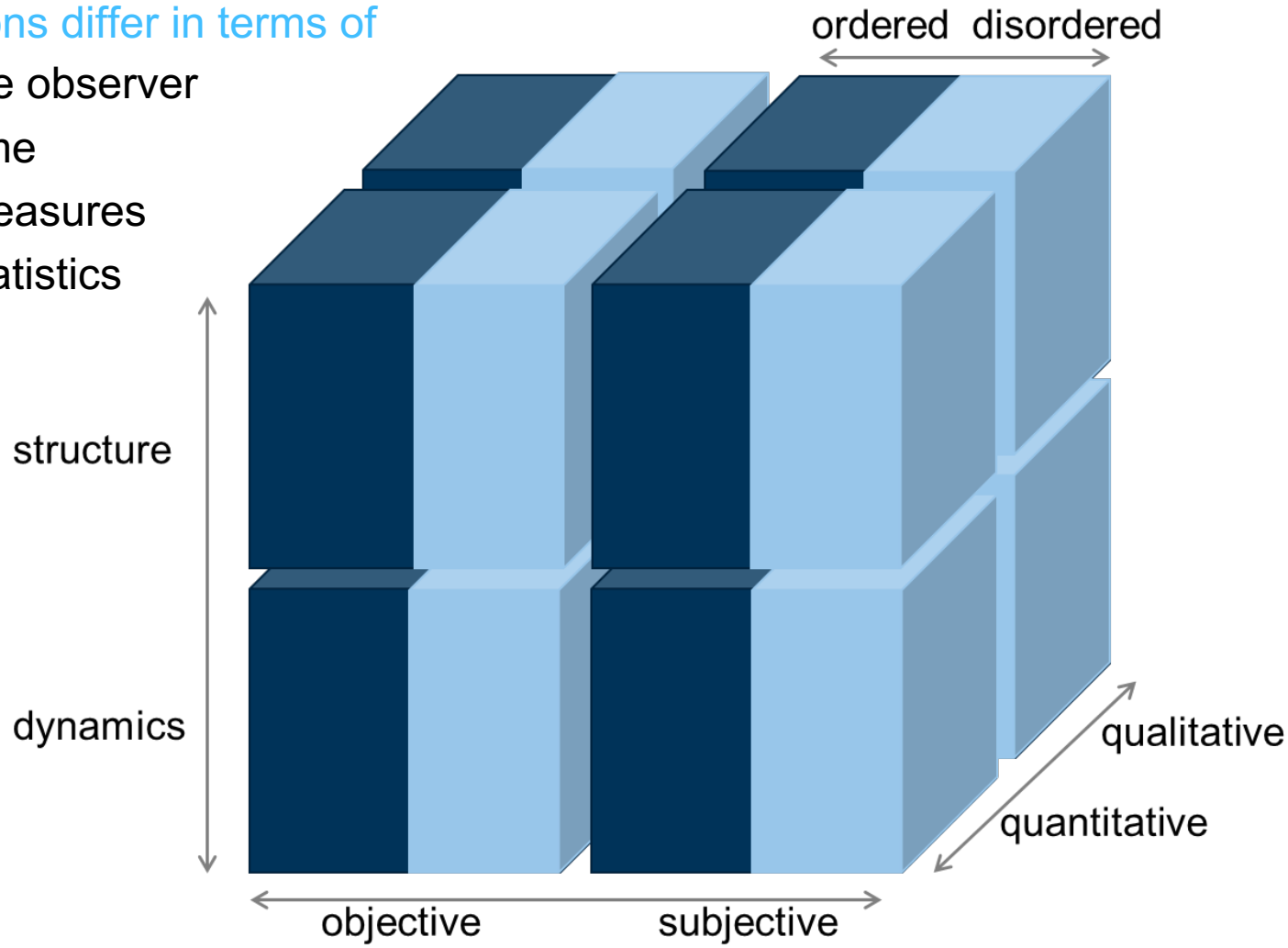
Complexity notions differ in terms of

- the role of the observer
- the role of time
- the role of measures
- the role of statistics



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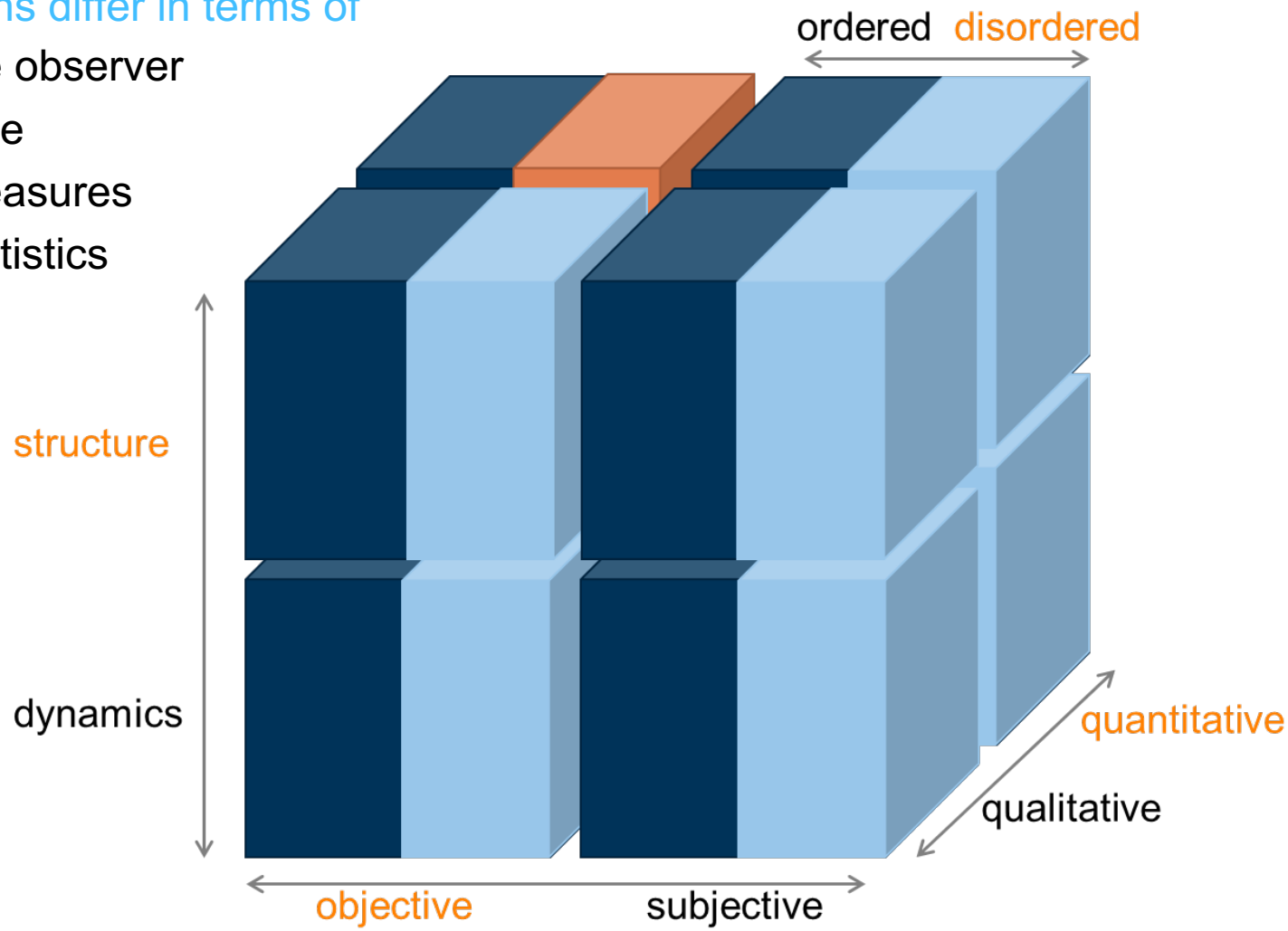

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Reoccurring AL Complexity Metrics in Practice

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Data collection

- 6 companies (Financial services and Automotive from Germany and Switzerland)
- More than 20 metrics found

Identified metric patterns

# Business Functions 3	# Applications 4	# Information Flows 6
# Infrastructure Components 4	Functional Redundancy 6	Standard Conformity 4

Usually calculated on both the application and the domain level

Schneider, Alexander W.; Reschenhofer, Thomas; Schuetz, Alexander; Matthes, Florian (2015): Empirical Results for Application Landscape Complexity. In: 48th Hawaii International Conference on System Sciences (HICSS). Kauai, HI, USA.

A generic information model for complexity measurements

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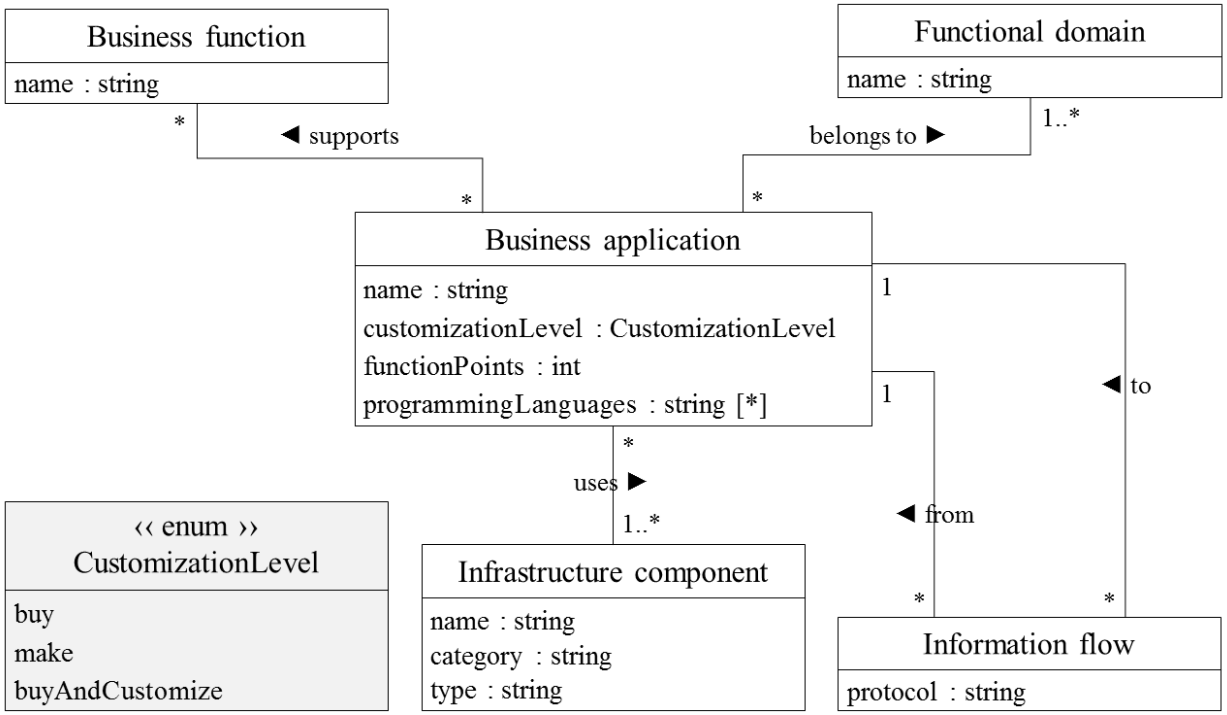
Information model



Model derivation

- Summary of all data necessary to calculate the 3 types of metrics
- Regards also actually available data in industry

Schneider, Alexander W.; Reschenhofer, Thomas; Schuetz, Alexander; Matthes, Florian (2015): Empirical Results for Application Landscape Complexity. In: 48th Hawaii International Conference on System Sciences (HICSS). Kauai, HI, USA.

Data quality and collection effort

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Case 1

- Financials (Switzerland)
- >10,000 employees

Case 2

- Financials (Germany)
- > 8,000 employees

Case 3

- Financials (Germany)
- > 52,000 employees

Case 4

- Financials (Germany)
- > 14,000 employees

Concept	C1	C2	C3	C4
Business application	432	247	1898	234
- customization level	100 %	89 %	100 %	100 %
- function points	–	99 %	24 %	98 %
- programming languages	–	45 %	–	72 %
- implements (Use Case)	–	–	–	–
- supports (Business function)	–	97 %	–	–
- belongs to (Functional domain)	100 %	99 %	87 %	100 %
- uses (Operating system)	–	67 %	90 %	83 %
- uses (Data base system)	–	48 %	60 %	67 %
Business function	–	580	–	–
Functional domain	13	16	33	41
Infrastructure component (Operating system)	–	9	15	12
- type	–	–	100 %	100 %
Infrastructure component (Date base system)	–	10	8	16
- type	–	–	–	–
Information flow	539	827	8252	1214
- protocol	100 %	–	100 %	100 %
- from (Business application)	100 %	100 %	100 %	100 %
- to (Business application)	100 %	100 %	100 %	100 %

Schneider, Alexander W.; Reschenhofer, Thomas; Schuetz, Alexander; Matthes, Florian (2015): Empirical Results for Application Landscape Complexity. In: 48th Hawaii International Conference on System Sciences (HICSS). Kauai, HI, USA.

Exemplary Results: Classification of Applications

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Class	A	B	C	D
Core	38,24%	55,47%	44,89%	36,75%
Control	14,12%	7,29%	7,11%	17,09%
Shared	8,24%	10,53%	13,33%	2,99%
Peripherie	39,41%	26,72%	34,67%	34,19%
Propagation cost	*24,39%*	*41,44%*	*30,28%*	*21,40%*

Changes of *Core* or *Shared* Applications might have unexpected impacts.

Schneider, Alexander W.; Reschenhofer, Thomas; Schuetz, Alexander; Matthes, Florian (2015): Empirical Results for Application Landscape Complexity. In: 48th Hawaii International Conference on System Sciences (HICSS). Kauai, HI, USA.

Results: Heterogeneity Metrics

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Calculated metrics (selection)

- Information flow protocol (Application & Domain)
- Customization level (Domain)
- Operating system (Domain)
- Database system (Domain/Landscape) [**C1**: -; **C2**: 5.2; **C3**: 4.7; **C4**: 3.1]
- Programming language (Domain)
- Coupled domains (Domain)

Identified cluster (correlation)

- Heterogeneity of Customization level, Database system & Operating system

No single metric correlates with the classification metric.

Schneider, Alexander W.; Reschenhofer, Thomas; Schuetz, Alexander; Matthes, Florian (2015): Empirical Results for Application Landscape Complexity. In: 48th Hawaii International Conference on System Sciences (HICSS). Kauai, HI, USA.

Results: Industry Metrics (selection)

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Application level

	C1	C2	C3	C4
#InformationFlows	[0;108], 2.5	[0;70], 6.7	[0;319], 8.7	[0;122], 10.4
#Infrastr.Components	-	[0;20], 4.7	[0; 22], 0.4	[0; 13], 3.9
#FunctionPoints	-	[1;34], 6.7	[1; 56], 7.3	[10;400], 178.9

([min;max], average)

Domain level

	C1	C2	C3	C4
#Applications	[6; 28], 14	[1; 53], 16	[1; 194], 50	[6; 88], 24.8
#InformationFlows	[10;195], 83	[1;390], 110	[0;1316], 491	[23;580], 281
#StandardConformity	[1.4;3.9], 3	[1.4; 5], 2.7	[1; 3.5], 2.5	[2; 3.3], 2.5

([min;max], average)

Schneider, Alexander W.; Reschenhofer, Thomas; Schuetz, Alexander; Matthes, Florian (2015): Empirical Results for Application Landscape Complexity. In: 48th Hawaii International Conference on System Sciences (HICSS). Kauai, HI, USA.

Interesting metric: Coupled domain heterogeneity

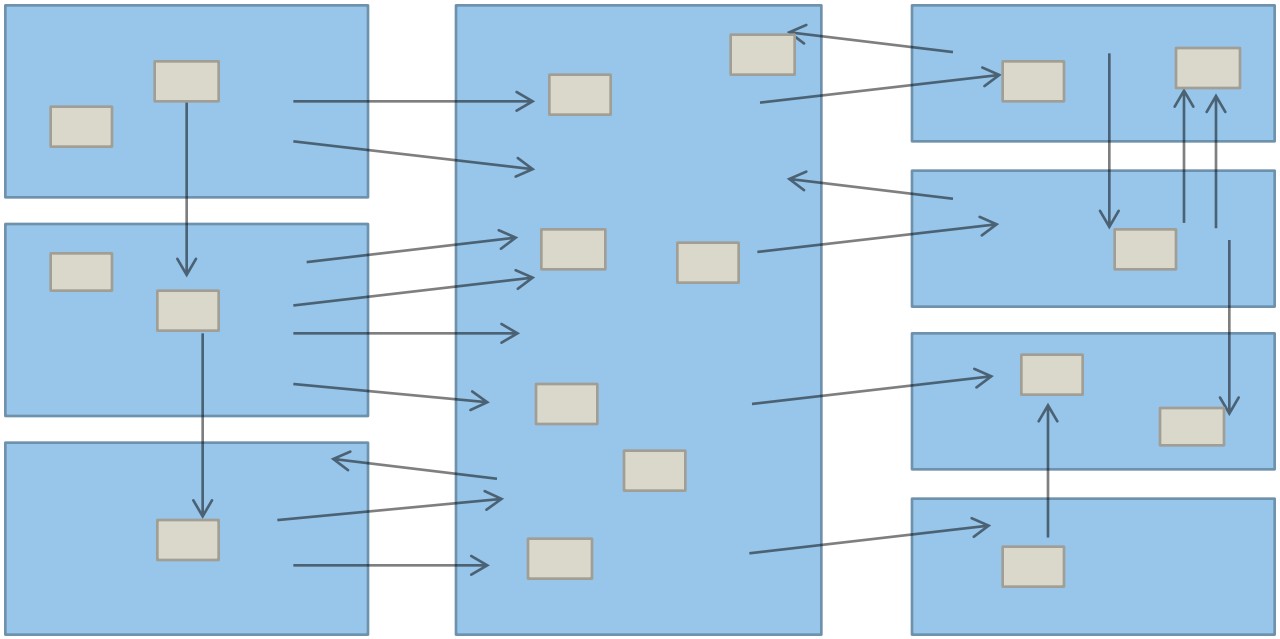
$$\forall \boldsymbol{d_1}, \boldsymbol{d_2} \in \boldsymbol{D}, \boldsymbol{d_1} \neq \boldsymbol{d_2}: \left[\boldsymbol{coupled}(\boldsymbol{d_1}, \boldsymbol{d_2}) \Leftrightarrow \exists \boldsymbol{a_1} \in \boldsymbol{A_{d_1}}, \exists \boldsymbol{a_2} \in \boldsymbol{A_{d_2}}: (\boldsymbol{a_1}, \boldsymbol{a_2}) \in \boldsymbol{I}\right]$$

A…Set of business applications

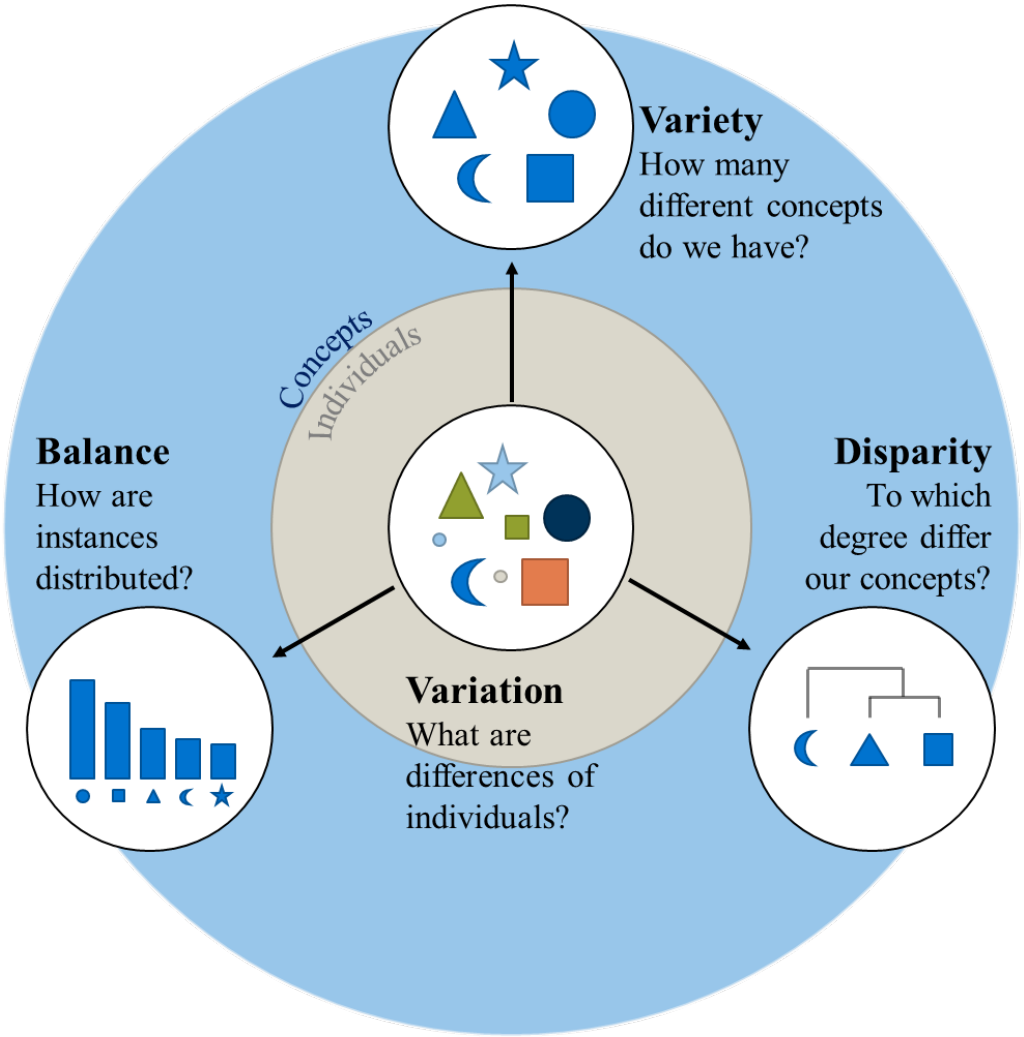
D…Set of domains

A_d…Applications of domain d

$I \subseteq A \times A$…Set of information flows, whereas (a_1, a_2) defines an information flow from application a_1 to application a_2



Aspects of Diversity



Stirling, Andy (2007): A general framework for analysing diversity in science, technology and society. In: Journal of the Royal Society Interface 4 (15), S. 707–719.
Page, Scott E. (2011): Diversity and complexity. Princeton, N.J: Princeton University Press (Primers in complex systems).

Contribution 1: Conceptual diversity framework

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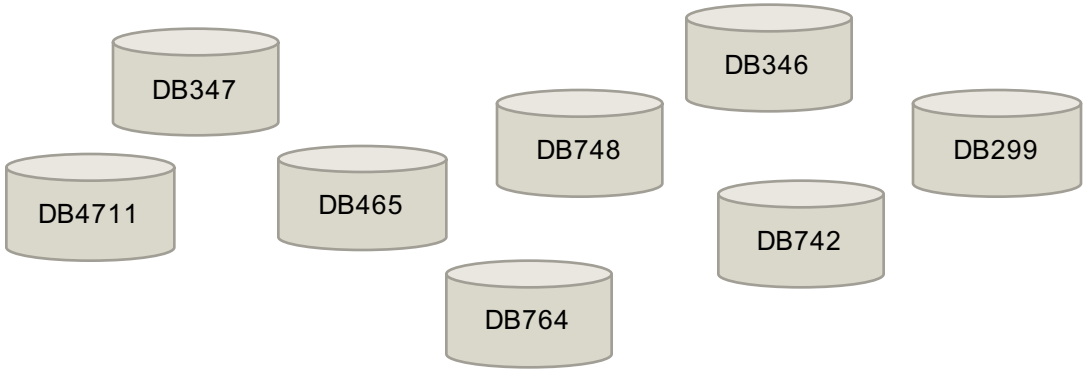
Diversity exemplified with Databases

Variation
What are differences between individuals?



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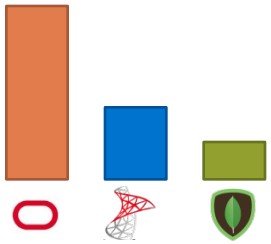
Contribution 1: Conceptual diversity framework

sebis

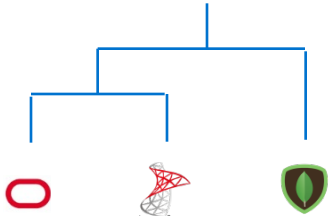
Diversity exemplified with Databases

Variety
How many different concepts do we have?

Balance
How are individuals distributed?



Disparity
To which degree do our concepts differ?



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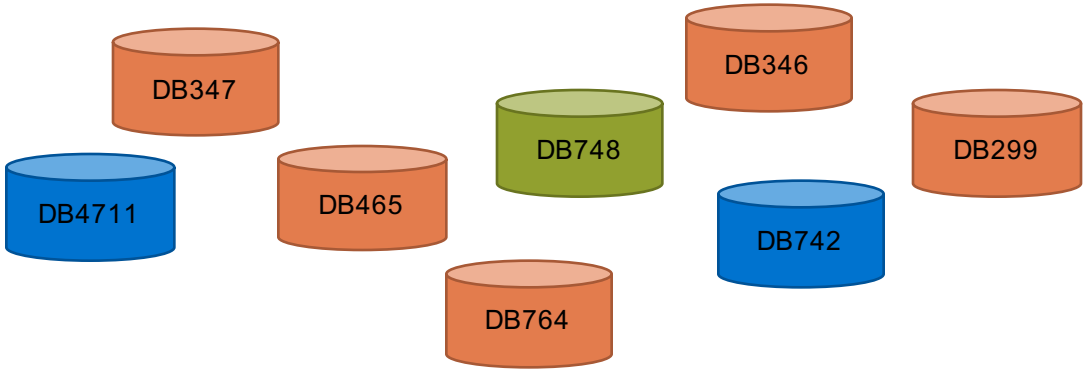

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Page, Scott E. (2011): Diversity and complexity. Princeton, N.J: Princeton University Press (Primers in complex systems).

Contribution 2: A novel metric to quantify balance

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Novel balance metric based on ordinal Skewness

- Entropy is a measure of concentration → context-free
- Skewness is applicable to ordinal data → context-sensitive

$$SO_X = -(k-1) + 2\sum_{i=1}^{k-1} P(X \leq x_i)$$

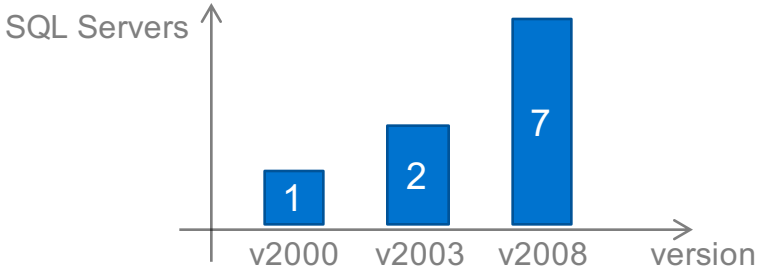
X : DB versions
k = |X|

Example: Versions of database systems

$SO_X = -(3-1) + 2\left(\frac{1}{10} + \frac{3}{10}\right) = -1.2$

Normalization:

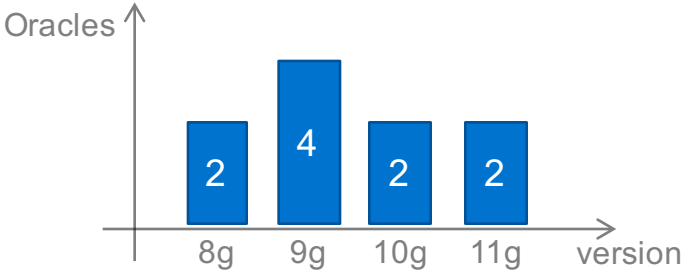
$\mathbf{SO_X^*} = -1.2 / 3 = \mathbf{-0.4}$



$SO_X = -(4-1) + 2\left(\frac{2}{10} + \frac{6}{10} + \frac{8}{10}\right) = 0.2$

Normalization:

$\mathbf{SO_X^*} = 0.2 / 4 = \mathbf{0.05}$



Ingo Klein. Systematik der Schiefemessung für ordinalskalierte Merkmale, 1999.
Schneider, A.W.; Schweda, C.M. and Matthes F.: Identifikation überalterter Komponenten in einer IT-Architektur, In: Multikonferenz Wirtschaftsinformatik (MKWI 2016), Ilmenau, Germany, 2016.

Contribution 3: A novel metric to quantify disparity

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Novel disparity metric based on Weitzman (1992)

- Distance of concepts is defined by a pair-wise distance function
- Provides decision support for concept extinction

$$V(S) = \max_{x \in S}\{V(S \setminus x) + d(x, S \setminus x)\}$$

S : Databases
x ∈ S

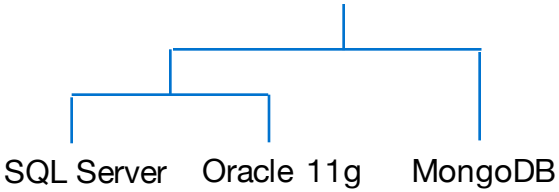
Exemplary distance function

	Oracle	SQL Server	MongoDB
Paradigm	SQL	SQL	NoSQL
License cost	High	Medium	Low

d(oracle,sql server) = 1
d(oracle,mongodb) = 3
d(sql server,mongodb) = 2

Exemplary Calculation

1. Let S equal the empty set and V(*S*) = 0
2. Chose a concept *y* of least distance to a member of *S* and add *y* to *S* (repeat)



V(*S*) = 3

Metric evaluation

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Selecting the case study method

- Research is at an early, formative stage (Roethlisberger, 1977)
- Research targets a practice-based problem where the experiences of the actors is important and the context of action is critical (Benbasat et al., 1987)

Evaluated artifacts

Case	Disparity	Balance	SW Prototype	Industry	FTEs
Case 1	●			Banking	>100,000
Case 2		●	●	Manufacturing	>20,000
Case 3	●	●	●	Insurance	>21,000
Case 4	●			Automotive	>230,000

Case study conduction

- Duration: Between 1 and 3 months
- Main partners: Enterprise architects, in 3 cases management involvement
- Access to company EA data

Metric evaluation results

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Case 3: Balance metric

- **Context**: Identification of adolescence in Operating Systems
- Six different products with up to eleven different releases

OS	v1	v2	v3	v4	v5	v6	v7	v8	v9	v10	v11	Balance
OS1	20	235										**-0.843**
OS2	243	3	77	2	397	5	6	5	1167	5	32	**0.019**
OS3	6	14										**-0.400**
OS4	2	1578	1496	1								**0.010**

- **Result**: Architects and manager were able to easily identify OS with adolescence

Case 4: Disparity metric

- **Context**: Diversification of Web Servers
- **Distance func** ce Acce port, Footprint
- **Result**: More structured and repeatable (incremental) approach than ad-hoc

Variety: Number of Different Types

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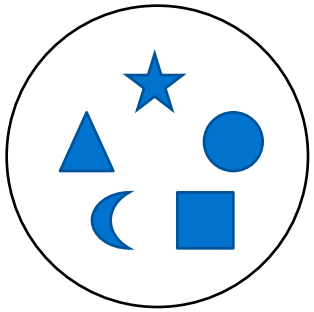
Diversity increases with the number of different types.



Example

- Oracle
- MS SQL Server
- MySQL

AL model A

- Oracle
- MS SQL Server
- MySQL
- DB2
- IMS
- Sybase
- MongoDB

AL model B

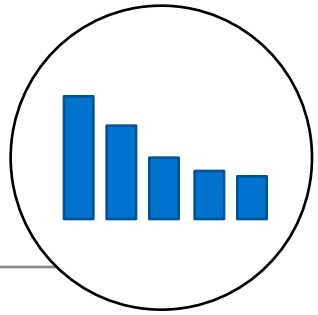
Typical metric

- Number of types
- Variety(A) = 3, Variety(B) = 7

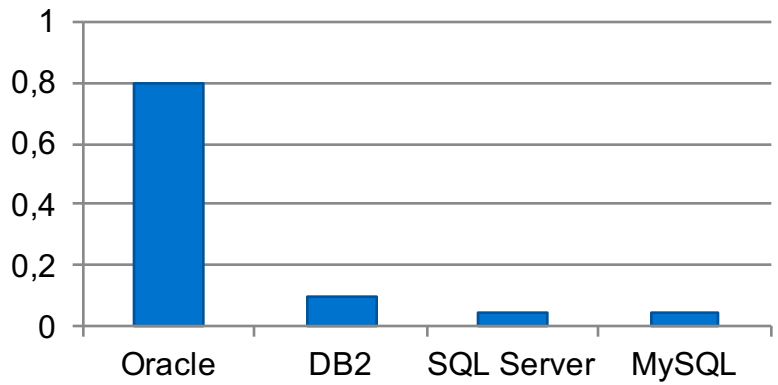
Mocker, Martin (2009): What is Complex about 273 Applications? Untangling Application Architecture Complexity in a case of European Investment Banking. In: 42nd Hawaii International Conference on System Sciences (HICSS): IEEE.
Schneider, Alexander W.; Reschenhofer, Thomas; Schuetz, Alexander; Matthes, Florian (2015): Empirical Results for Application Landscape Complexity. In: 48th Hawaii International Conference on System Sciences (HICSS). Kauai, HI, USA.

Balance: Instance Distribution among Types

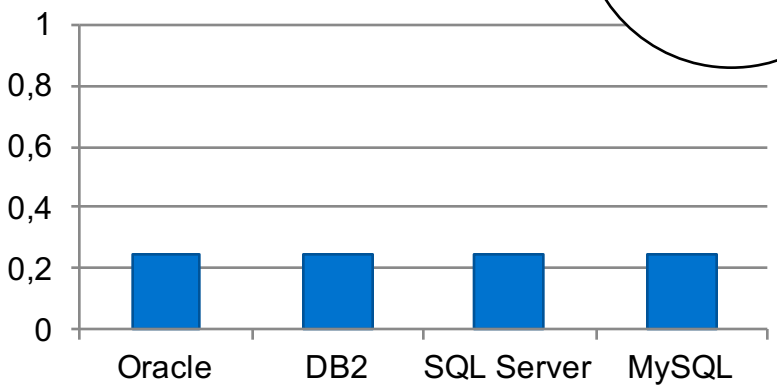
Diversity increases the more balanced the distribution is.



Example



EM = 0.7 EM_A = 2



EM = 1.39 EM_A = 4

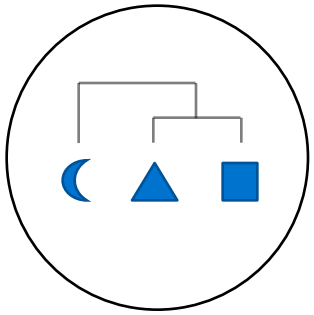
Typical metric

- Shannon Entropy $$-\sum_{i=1}^{n} p_i \, ln(p_i)$$

Schütz, A.; Widjaja, T.; Kaiser, J. (2013). Complexity in Enterprise Architectures - Conceptualization and Introduction of a Measure from a System Theoretic Perspective. European Conference on Information Systems (ECIS); Utrecht, Netherlands.

Disparity: Difference among Concepts

Diversity increases when the distance among types increases.



Example

Alligator

Crocodile

Caiman

Alligator

Elephant

Piranha

Typical metric

- Weitzman metric $\max_{x \in S}\{V(S \backslash x) + d(x, S \backslash x)\}$

Weitzman, Martin L. (1992): On diversity. In: *The Quarterly Journal of Economics*, S. 363–405.

A Novel Metric to Quantify Disparity

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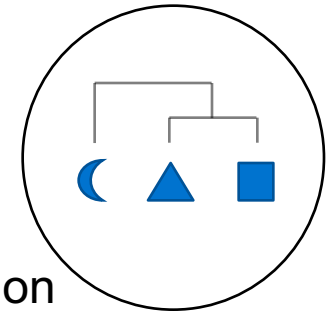


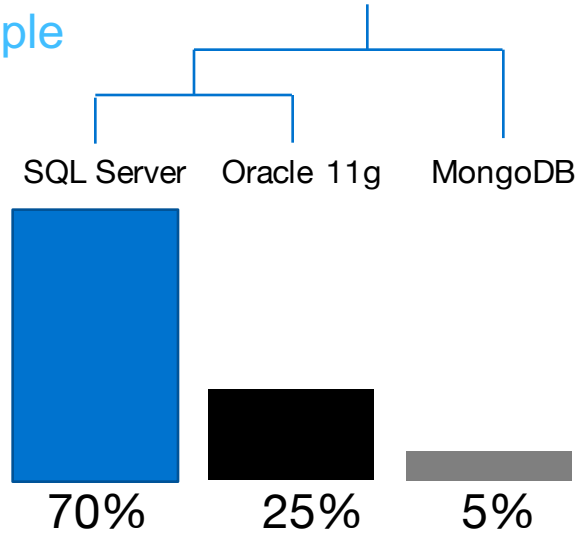
Limitation of current approaches

- Disparity has not been considered yet in EA

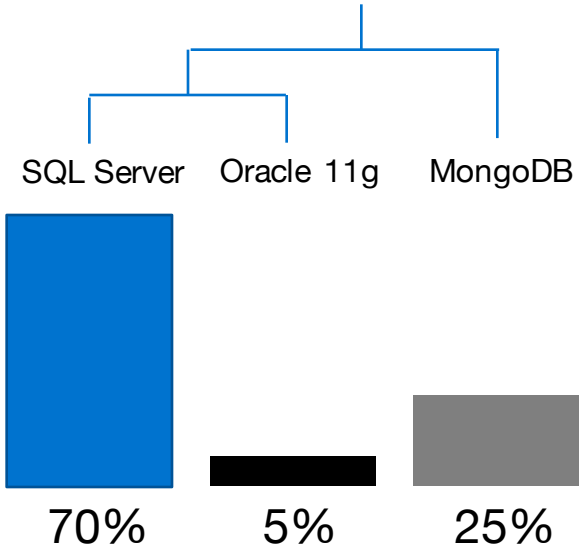
Novel metric based on Weitzman (1992)

- Distance among concepts is defined by a pair-wise distance function
- Calculated by incrementally increasing it by the distance value to the closest concept
- Provides decision support for concept extinction while maximizing diversity

Example



DBMS model A



DBMS model B

How to Calculate Disparity?

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Step 1: Element assessment

- Identify aspects contributing to disparity
- Assess each element regarding these aspects

Example: Database disparity

- Paradigm (SQL vs. NoSQL)
- Use case (OLTP vs. OLAP)
- Cost (cheap vs. expensive)

Element	SQL	NoSQL	OLTP	OLAP	Cheap	Expensive
SQL Server	yes	no	yes	no	yes	no
DB2	yes	no	yes	no	no	yes
Oracle	yes	no	yes	no	no	yes
IMS	no	yes	no	no	no	yes
Sybase	no	yes	no	yes	no	yes

How to Calculate Disparity?

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Step 2: Distance calculation

- Here Euclidean distance: yes = 1 and no = 0
- $d(x,y) = SUM[(x_i - y_i)^2]^{1/2}$

Example: Database disparity

Element	SQL Server	DB2	Oracle	IMS	Sybase
SQL Server	0				
DB2	1,41	0			
Oracle	1,41	0	0		
IMS	2	1,41	1,41	0	
Sybase	2,45	2	2	1,41	0

Disparity:
1,41

SQL Server DB2

How to Calculate Disparity?

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How to Calculate Disparity?

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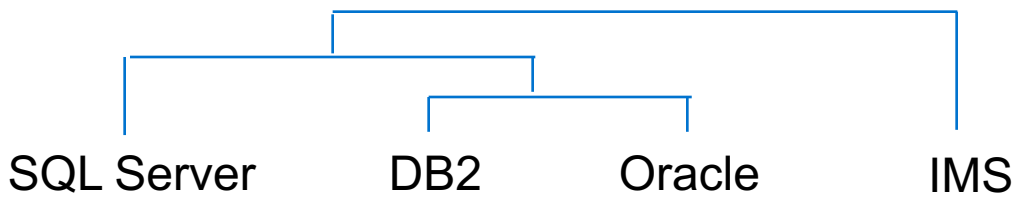
Disparity:
2,82



How to Calculate Disparity?

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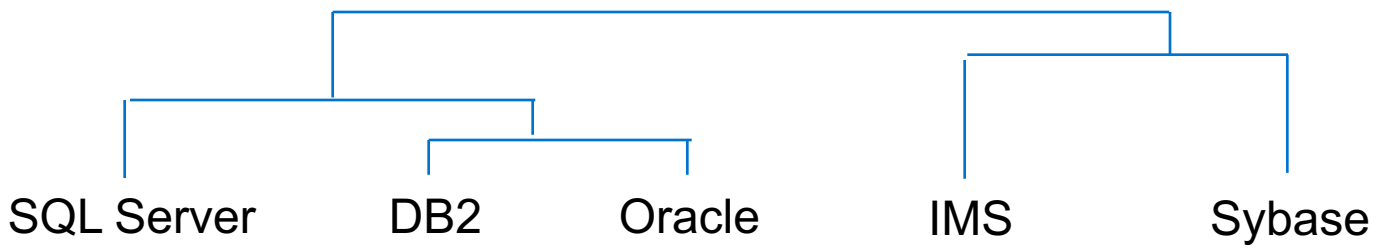

Disparity:
3,23

CALM^3 Diversity Assessment for Databases

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Diversity aspect	Case 1	Case 2	Case 3
Variety	8	10	8
Balance	1.653	1.568	1.122
Balance (normalized)	5.227	4.795	3.074
Disparity	8.485	8.485	11.314

Criteria used to calculate distance among types

- Paradigm (SQL vs. NoSQL)
- Use case (OLTP vs. OLAP)
- Cost (cheap vs. expensive)

CALM^3 Diversity Assessment for Databases

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Domain (DBMS instances)	Variety	Balance	Disparity	Disparity (weighted)	Types
Compliance Services (4)	2	0.693	2.83	2.83	MS SQL, Oracle
Operational Risk (2)	2	0.693	2.83	4	Sybase, Oracle
Product Conditions (4)	2	0.693	2.83	2,83	DB2, IMS
Legal (2)	2	0.693	4	4.90	MS SQL, Sybase
Enterprise App. Integration (2)	2	0.693	0	0	DB2, Oracle
Technical Services (2)	2	0.693	2.83	2.83	Oracle, IMS

In-depth analysis of case 2

- Variety and balance are equal for all of these domains
- Concrete types of used database systems differ significantly
- Disparity highlights potential standardization areas

Diversity metrics implementation

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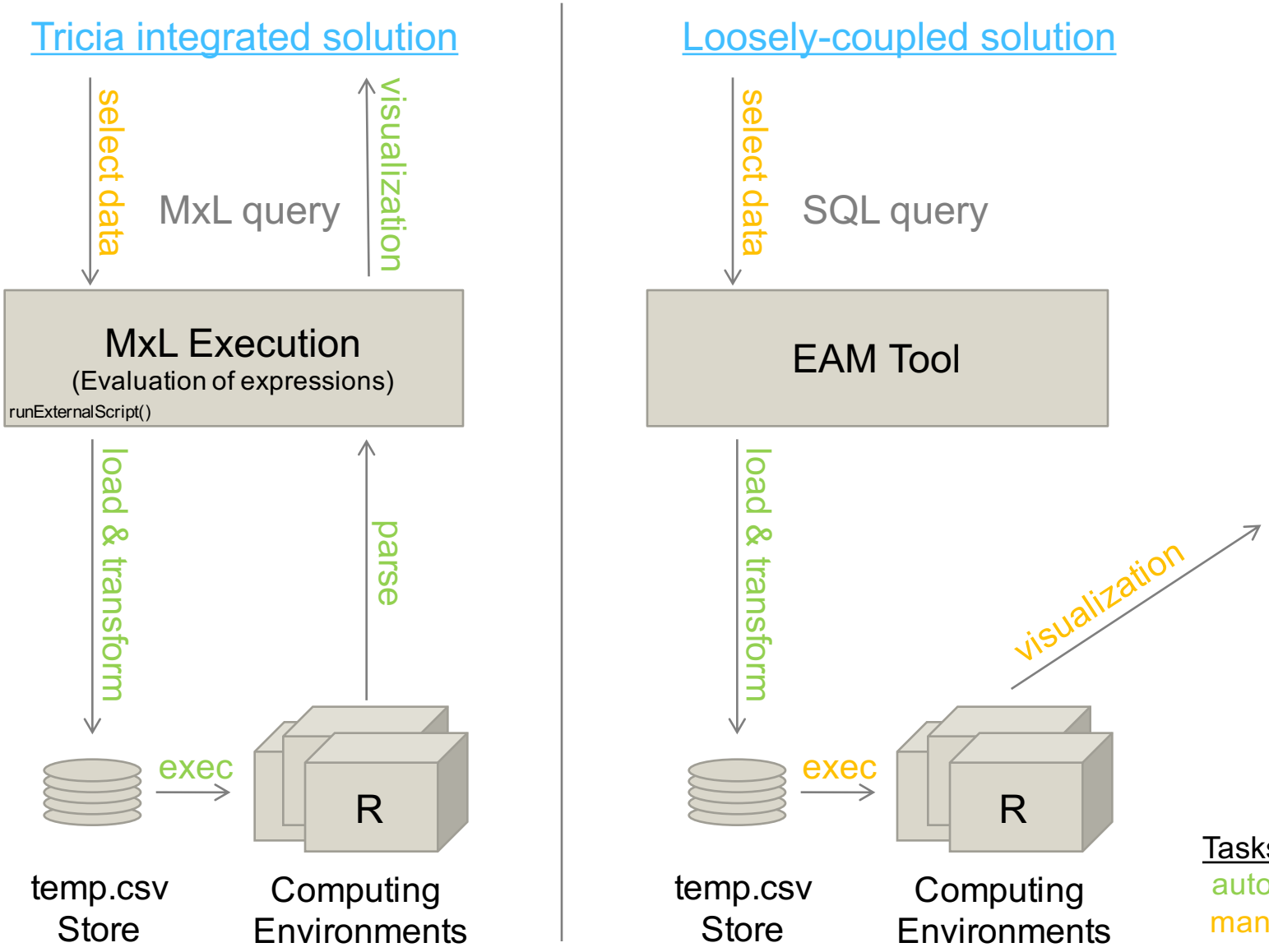

A General Distance Function for DBMS

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Used criteria:

- Paradigm (SQL vs. NoSQL)
- Use case (OLTP vs. OLAP)
- Cost (cheap vs. expensive)

Evaluation

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Case study candidates

Allianz

UniCredit

DAIMLER

ZEISS

Questions to be answered

- Do identified benefits and drawbacks support decisions regarding desired diversity?
- Are all relevant aspects of diversity covered by the conceptual framework?
- Do diversity metrics yield new insights thus supporting diversity decisions?
- Is it possible to develop appropriate distance functions?
- Is the novel disparity metric necessary to complement existing metrics?
- Does the proposed software support meet practitioners requirements?

Diversity dependencies across EA layers

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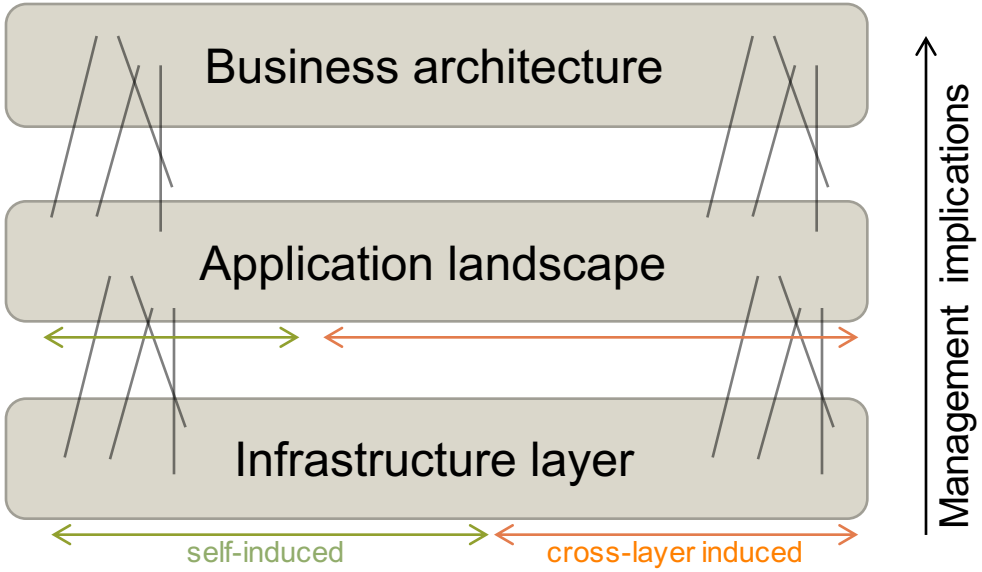
Cross-layer induced diversity

- In case of dependencies between elements of different architectural layers diversity can be considered *cross-layer induced*.
- Example: Applications A and B use custom functionality of different databases.

Self-induced diversity

- In case of consistent interfaces and zero disparity the diversity can be considered *self-induced.*
- Example: Applications C and D both require a relational database.



Summary

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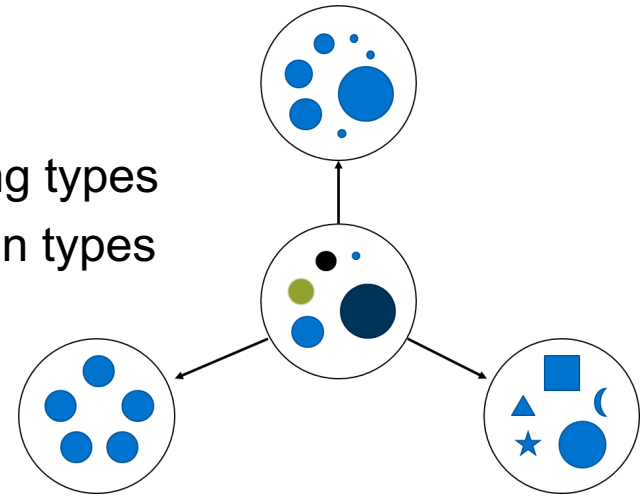
Diversity reasons and consequences are manifold

- Business requirements
- Legal requirements
- Technological progress
- …

- Costs
- Increasing time-to-market
- Potential for innovation
- …

Diversity contributes significantly to complexity

- Variety covers the amount of types
- Balance covers the distribution of instances among types
- Disparity covers the degree of differences between types



Diversity assessment/measurement is essential for its management

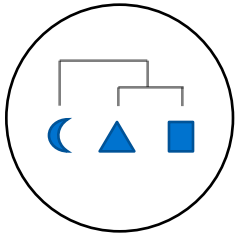
Summary

- AL diversity: enable organizational agility and keep costs under control
- Diversity consists of four dimensions:

Variation

Variety

Balance



Disparity

- Two metrics for their quantification have been developed and implemented
- Applicability validated in four case studies
- Examination of the relationship between AL diversity and AL complexity
- Identification of steering mechanisms for enterprise architects

Future Research

- Observe metric behavior in more detail
- Investigate relationships between diversity and other IT related aspects
- Develop a governance model for application landscape diversity management

Summary & Future work

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Conclusion

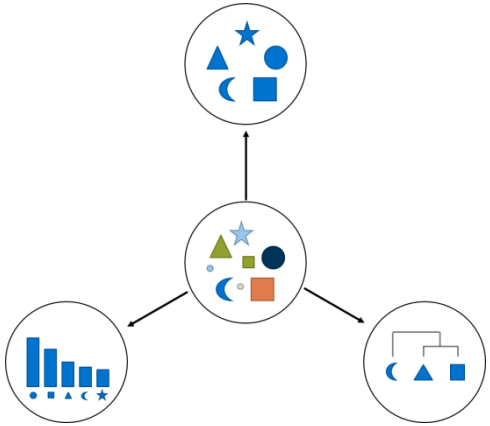
- Up to now, literature provides three different approaches to measure EA complexity
- Practitioners developed additional useful metrics
- Necessary information for calculation is usually available
- Complexity metric values differ significantly in practice
- Model and domain design limits comparability
- Each type of metric has its own benefits and drawbacks

Open questions

- What are desirable target values for complexity metrics?
- How does complexity evolve over time?
- Can we identify the impact of a certain business architecture on the application landscape complexity?

Conclusion

- **Diversity** is one aspect of **complexity** that seems to be particularly relevant for application landscape management
- Diversity should be studied independently from complexity
- Diversity can be further broken down into variety, balance, and disparity
  - **Variety** covers the number of different types
  - **Balance** covers the distribution of instances among types
  - **Disparity** covers the degree of differences between types



  - Calculation of disparity requires additional information about distances
  - Required effort: Proportional to the number of types squared

Thank you for your attention. Questions?

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