Departamento de Informática
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DEFINING AND VALIDATING METRICS FOR CONCEPTUAL MODELS

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INTRODUCTION

- Building quality IS is one of the most pressing challenges that faces software organisations today
- The quality of IS is highly dependent on decisions made early in its development
- Conceptual model quality is a major determinant of the quality of the overall IS design
- Metrics are necessary to evaluate conceptual model quality in an objective and quantitative way

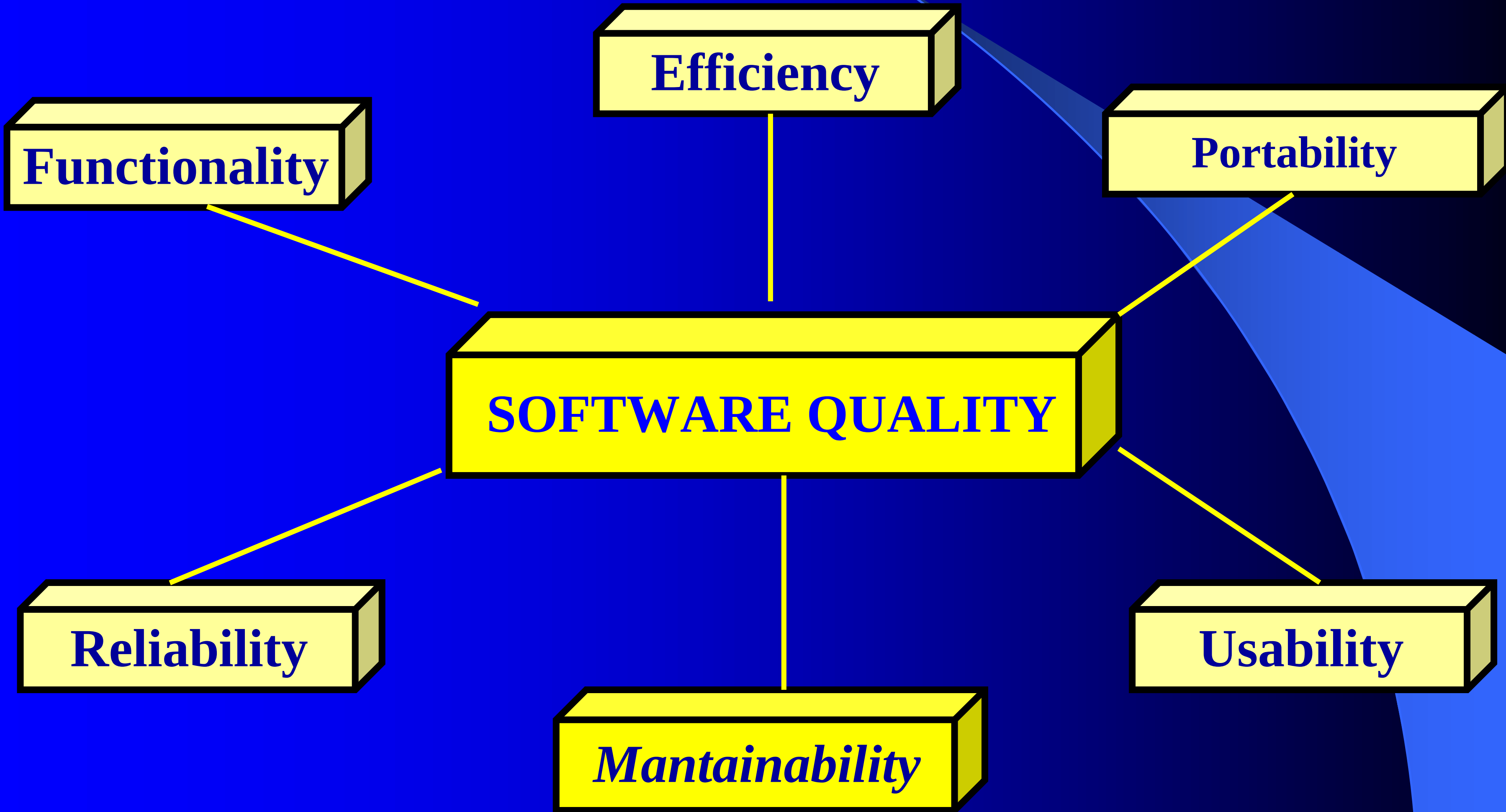
INTRODUCTION

The early availability of metrics allow IS designers:

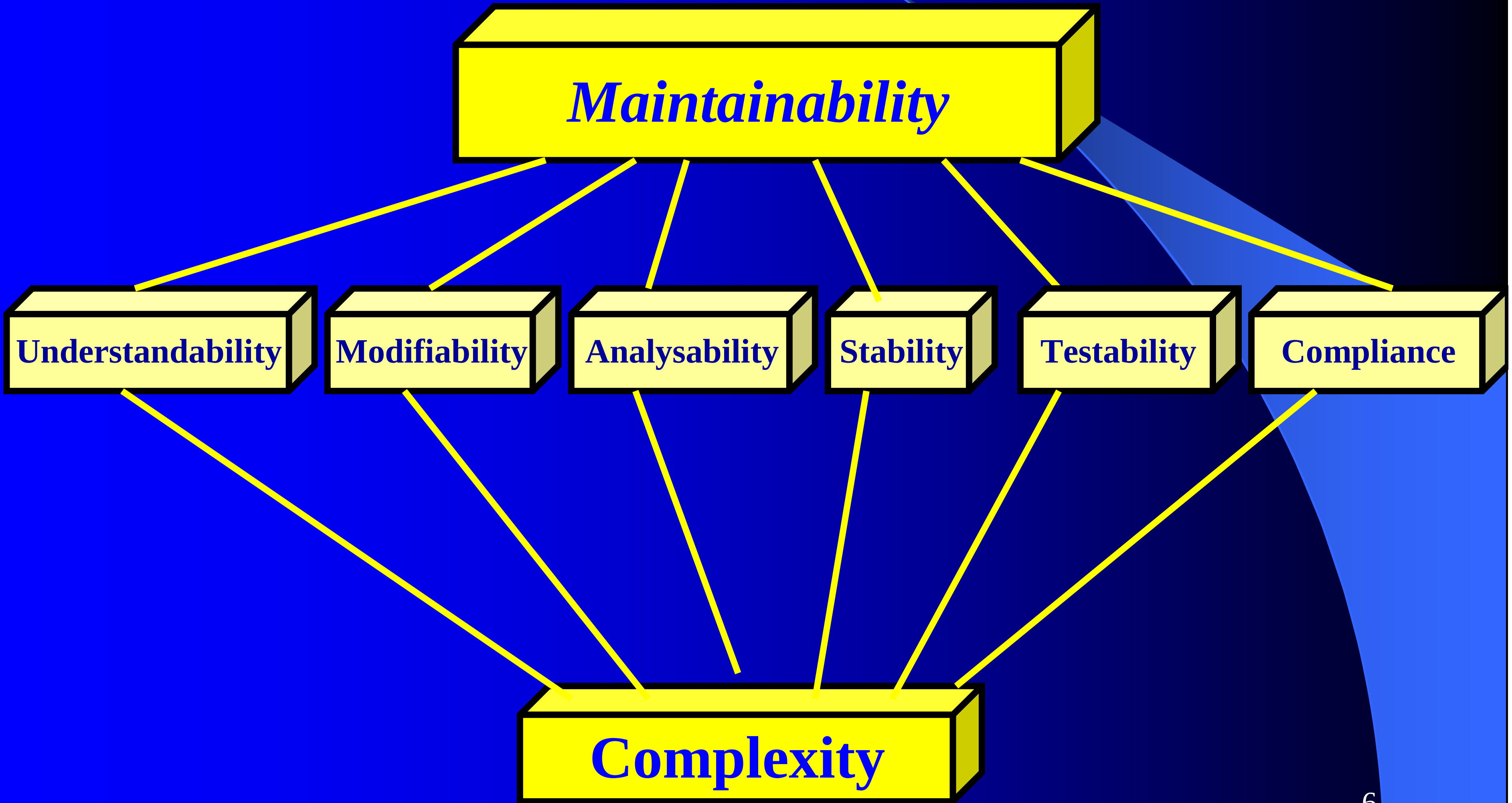
- a quantitative comparison of design alternatives
- a prediction of external quality characteristics

INTRODUCTION

ISO 9126

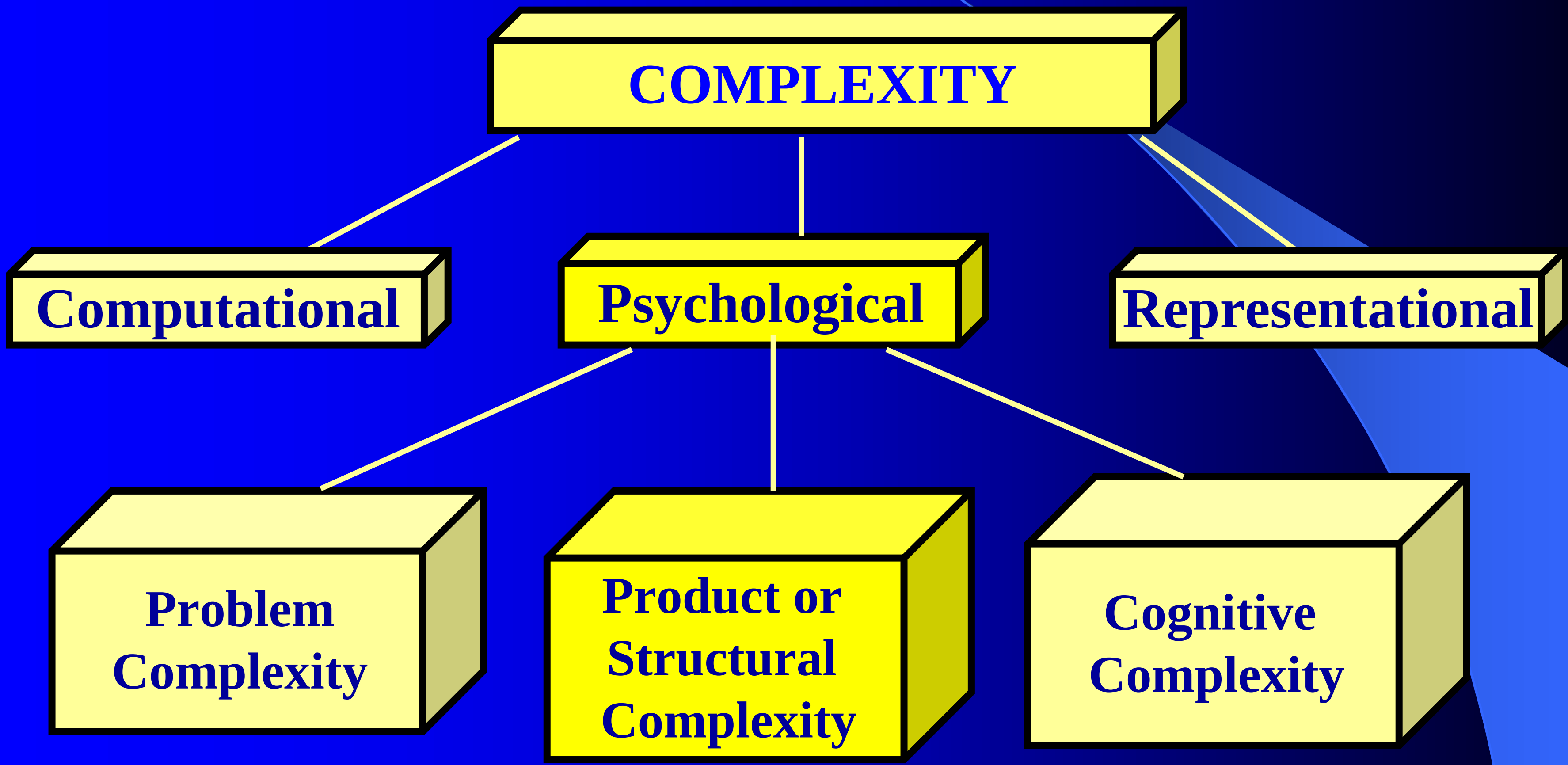


INTRODUCTION



INTRODUCTION

Henderson-Sellers (1996)



INTRODUCTION

We consider two types of conceptual models:

- Traditional conceptual models
- OO conceptual models

INTRODUCTION: Main objective

DEFINE A SET OF METRICS TO ASSESS AND CONTROL THE MAINTAINABILITY OF TRADITIONAL AND OO CONCEPTUAL MODELS

INTRODUCTION: Partial objectives

1. Analyse the existing metrics
2. Define a method for the definition of valid metrics
3. Define a set of metrics
4. Study measurement formal frameworks
5. Perform the theoretical validation
6. Study the different empirical strategies
7. Perform the empirical validation
8. Design and develop a tool prototype

INTRODUCTION: Hypothesis

IT IS FEASIBLE TO DEFINE METRICS TO ASSESS AND CONTROL THE MAINTAINABILITY OF TRADITIONAL AND OO CONCEPTUAL MODELS

INTRODUCTION: Thesis framework

- The MANTICA project: *Definition of a set of metrics for the maintainability of object-relational databases*

Financed jointly by the FEDER of the European Union and the Interministerial Commission of Science and Technology CICYT-FEDER, 1FD97-0168 (1997-2001)

INTRODUCTION: Thesis framework

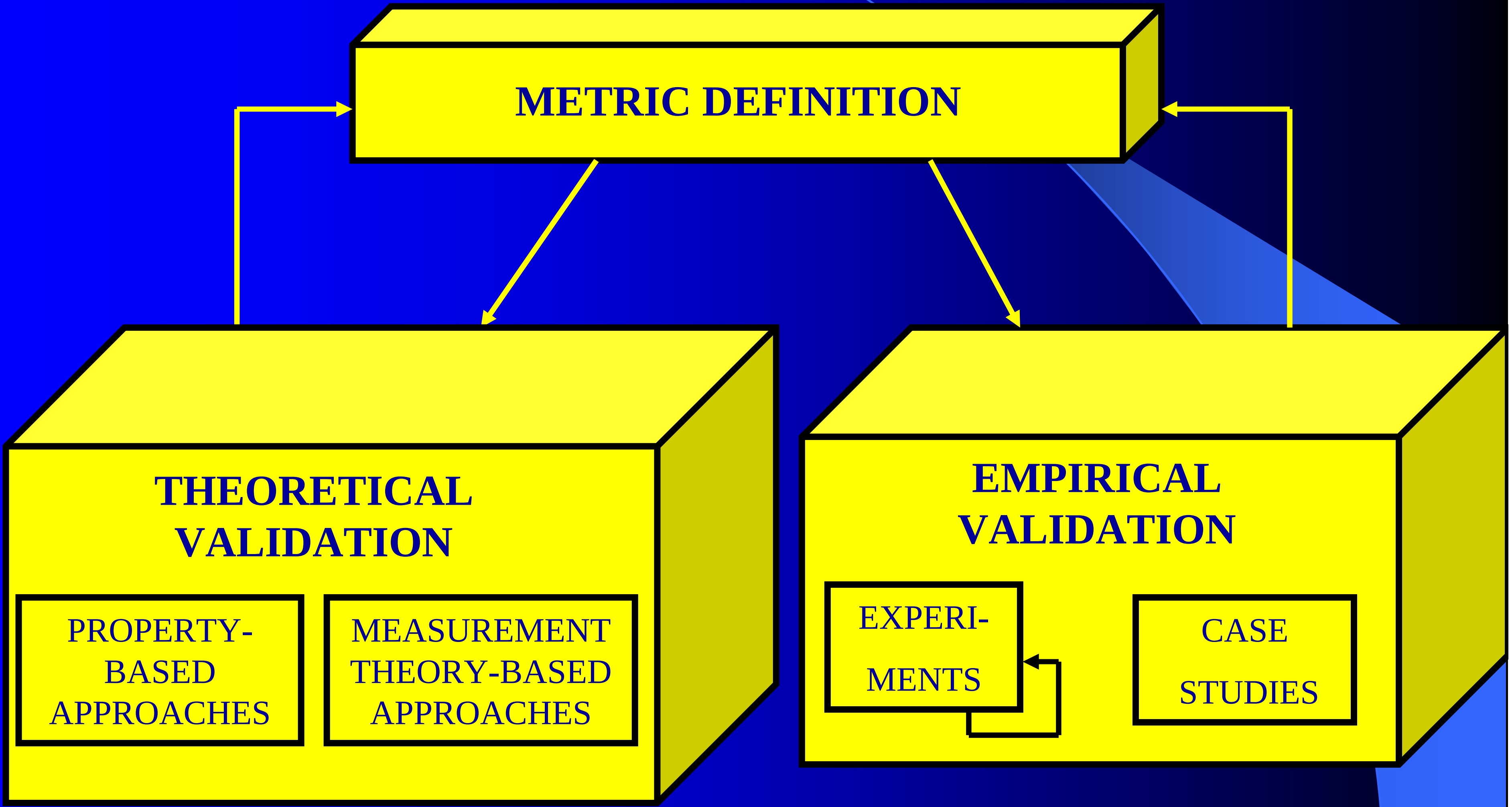
- The DOLMEN/MEDEO Project: *Improvement in the development of objects*

  Developed by different research groups belonging to six Spanish universities: Seville, Valladollid, Murcia, Granada, Valencia and Castilla-La Mancha

  Financed by the Ministry of Science and Technology (2000-2003)

CONTENTS

RESEARCH METHOD



RESEARCH METHOD: Metric Definition

- Metrics must be defined in a methodological way

- Metrics must be based on IS designers experience

RESEARCH METHOD: Theoretical validation

- The main goal of theoretical validation is to check if the intuitive idea of the attribute being measured is reflected in the measurement
- Unfortunately, there is not yet a standard, accepted way of theoretically validating a measure (Van Den Berg and Van Den Broek, 1996)
- Work on theoretical validation has followed two paths:
  - property-based approaches
  - measurement theory-based approaches

RESEARCH METHOD: Property-based approaches

- Formally define desirable properties of the measures for a given software attribute
- They aim to formalise the empirical properties that a generic attribute of software must satisfy
- Propose a measure property set that is necessary but not sufficient
- The best known of these are those proposed by Weyuker (1988), Briand et al. (1996) and by Morasca and Briand (1997)

RESEARCH METHOD: Measurement Theory - based approaches

- Are used to check for a specific measure if the empirical relations between the elements of the real world established by the attribute being measured, are respected when measuring the attributes
- Gives clear definitions of terminology, a sound basis of software measures, empirical properties of software measures, and criteria for measurement scales
- The most well known of these are those proposed by Zuse (1998) and Poels and Dedene (1999; 2000)

RESEARCH METHOD: Briand et al.´s framework (1996; 1997)

Size
Length
Complexity
Cohesion
Coupling

RESEARCH METHOD: Zuse´s framework (1998)

Applying the Zuse´s framework we can conclude that:

- If a metric complies with the weak order, it can be classified according to the ordinal scale
- If a metric complies with the modified extensive structure and also with the independence conditions, it can be classified according to the ratio scale
- If a metric does not satisfy the extensive structure but does the independence conditions, it can be classified according to the ordinal scale
- If a metric complies with the modified structure of belief, it could be characterised above the ordinal scale but without reaching the ratio scale

RESEARCH METHOD: Poels and Dedene´s framework (1999)

- Provides constructive procedures to model software attributes and define the corresponding measures
- Software attributes are modelled as conceptual distances
- The distances are measured by functions that are called “metrics” in mathematics
- These functions satisfy a set of axioms that are necessary and sufficient to define measures of distance
- Ensure the construct validity of the resulting measures
- The resulting measures are characterised by the ratio scale type

RESEARCH METHOD:
Poels and Dedene´s framework (1999)

Steps	Inputs	Outputs
1. Find a measurement abstraction	The attribute of interest *attr* A set of software entities P	A set of software entities M (to be used as measurement abstractions) A function *abs*: $P \to M$
2. Model distances between measurement abstractions	M	A set of elementary transformation types T_e
3. Quantify distances between measurement abstractions	M, T_e	A metric δ: $M \times M \to \Re$
4. Find a reference abstraction	*Attr*, P, M	A function *ref*: $P \to M$ (to return a reference abstraction for *attr*)
5. Define the software measure	P, *abs*, δ, *ref*	A function μ: $P \to \Re$

RESEARCH METHOD: Empirical validation

- Common wisdom, intuition, speculation, and proof of concepts are not reliable sources of credible knowledge (Basili et al., 1999)
- The empirical studies are necessary to confirm and understand the implications of the measurement of our products
- For the empirical studies to be really useful it is necessary to create better studies and draw more credible conclusions from them (Perry et al., 2000)

RESEARCH METHOD: Empirical validation

There are three major types of empirical investigations:

- experiments
- case studies
- surveys

RESEARCH METHOD: Empirical Validation

EMPIRICAL STRATEGIES COMPARISON

FACTOR	SURVEY	CASE STUDY	EXPERIMENT
Execution control	No	No	Yes
Measurement control	No	Yes	Yes
Investigation cost	Low	Medium	High
Ease of replication	High	Low	High

RESEARCH METHOD: Experiments

Experiment Idea

EXPERIMENT PROCESS (Wohlin et al., 2000)

DEFINITION

PLANNING

OPERATION

ANALYSIS & INTERPRETATION

VALIDITY EVALUATION

PRESENTATION & PACKAGES

Conclusions

RESEARCH METHOD: Replication of experiments

- The replication of experiments is essential (Basili et al., 1999)
- It is necessary the creation of lab packages
- Brooks et al. (1996) distinguish:
  - Internal replication
  - External replication

RESEARCH METHODS: Advanced techniques for data analysis

- Classical statistical tests

- Advanced techniques:
  - Fuzzy Clasification and Regression Trees (FCART) (Linares et al., 1996)
  - Fuzzy Prototypical Knowledge Discovery (FPKD) (Olivas, 2000)

CONTENTS

- Introduction
- Research Method
- **State of the Art**
- Metric Definition
- Metric Validation
- MANTICA Tool
- Conclusions
- Future work

STATE OF THE ART

We grouped the different proposals existing in the literature which deals with the quality of conceptual models in the following way:

- **Quality criteria**
- **Quality frameworks**
- **Quality metrics**

STATE OF THE ART

- **Quality criteria**
  - Batini et al. (1992)
  - Reingruber and Gregory (1994)
  - Boman et al. (1997)
- **Quality frameworks**
  - Krogstie et al. (1995)
  - Moody et al. (1998)
  - Kesh (1995)
  - Schuette and Rotthowe (1998)

STATE OF THE ART

- **Quality metrics for traditional conceptual models**
  - Kesh (1995)
  - Moody (1998)
  - Gray (1991)
  - Eick (1991)
- **Quality metrics for OO conceptual models**
  - Chidamber and Kemerer (1994)
  - Brito e Abreu and Carapuça (1994)
  - Lorenz and Kidd (1994)
  - Marchesi (1998)

STATE OF THE ART

SUMMARY OF METRICS FOR TRADITIONAL CONCEPTUAL MODELS

Authors	Focus	Scope	Objective/ Subjcetive	Theoretical Validation	Empirical Validation	Tool
Eick (1991)	Expressiveness, complexity, normalizedness	S-diagrams	Objective	N	N	N
Gray (1991)	Complexity , Deviation from 3FN	ER diagrams	Objective	Partially	Partially	Y
Kesh (1995)	Ontological quality and Behavioural quality	ER diagrams	Objective and Subjective	N	N	Y
Moody (1998)	Completeness, integrity, flexibility, understandability, correctness, simplicity, integration, implementability	ER diagrams	Objective and Subjective	Partially	N	Y

STATE OF THE ART

SUMMARY OF METRICS FOR OO CONCEPTUAL MODELS

Authors	Focus	Scope	Objective/ Subjective	Theoretical Validation	Empirical Validation	Tool
Chidamber and Kemerer (1994)	Complexity	Class	Objective	Y	Partially	Y
Lorenz and Kidd (1994)	Static characteristic of OO designs	Class/ Class diagram	Objective	N	Partially	Y
Brito e Abreu and Carapuça (1994)	Measure the use OO design mechanisms such as inheritance, information hiding, coupling and polymorphism	Class diagram	Objective	Y	Partially	Y
Marchesi (1998)	System complexity, balancing of responsibilities among packages and classes, and cohesion and coupling among system entities	Class/Class diagram	Objective	N	Partially	Y

STATE OF THE ART

There is a need of VALID metrics for:

- Traditional conceptual models (ERDs)
- OO conceptual models (Class diagrams)

⇓

ASSESS AND CONTROL QUALITY IN AN OBJECTIVE WAY

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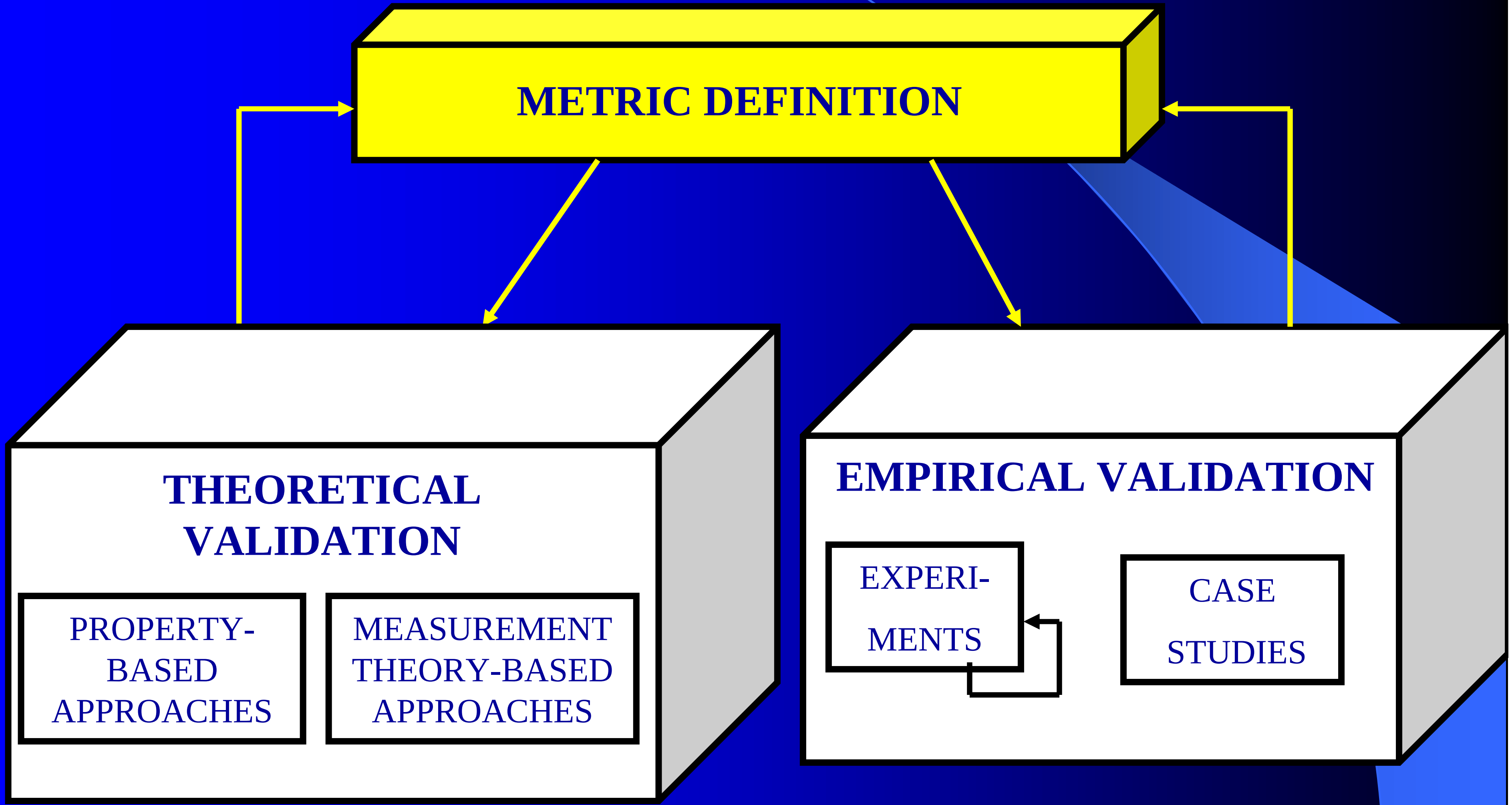
METRIC DEFINITION



METRIC DEFINITION: Traditional conceptual models

GOAL

Analyse	*ER diagrams*
for the purpose of	*Evaluating*
with respect to their	*Maintainability*
from the point of view of the	*Software designers*
in the context of	*Software delevopment organisations*

METRIC DEFINITION: Definition of metrics for ER diagrams

- Number of entities (NE)
- Number of attributes (NA)
- Number of derived attributes (NDA)
- Number of composite attributes (NCA)
- Number of multivalued attributes (NMVA)
- Number of relationships (NR)
- Number of M:N relationships (NM:NR)
- Number of 1:N relationships (N1:NR)

METRIC DEFINITION:
Definition of metrics for ER diagrams

- Number of N-Ary relationships (NN-AryR)
- Number of binary relationships (NBinaryR)
- Number of IS_A relationships (NIS_AR)
- Number of reflexive relationships (NRefR)
- Number of redundant relationships (NRR)

METRIC DEFINITION: OO conceptual models

GOAL

Analyse	*UML Class diagrams*
for the purpose of	*Evaluating*
with respect to their	*Maintainability*
from the point of view of the	*Software designers*
in the context of	*Software delevopment organisations*

METRIC DEFINITION: Definition of metrics for class diagrams

CLASS DIAGRAMS-SCOPE METRICS

- Number of associations (NAssoc)
- Number of aggregations (NAgg)
- Number of aggregation hierarchies (NAggH)
- Maximum height of aggregation (MaxHagg)
- Number of generalisations (NGen)
- Number of generalisation hierarchies (NGenH)
- Maximum depth of inheritance (MaxDIT)
- Number of dependencies (NDep)

METRIC DEFINITION: Definition of metrics for class diagrams

CLASS-SCOPE METRICS

- Number of associations per class (NAssocC)
- Height of aggregation (HAgg)
- Number of direct parts (NDP)
- Number of parts (NP)
- Number of wholes (NW)
- Number of dependencies IN (NDepIN)
- Number of dependencies OUT (NDepOUT)

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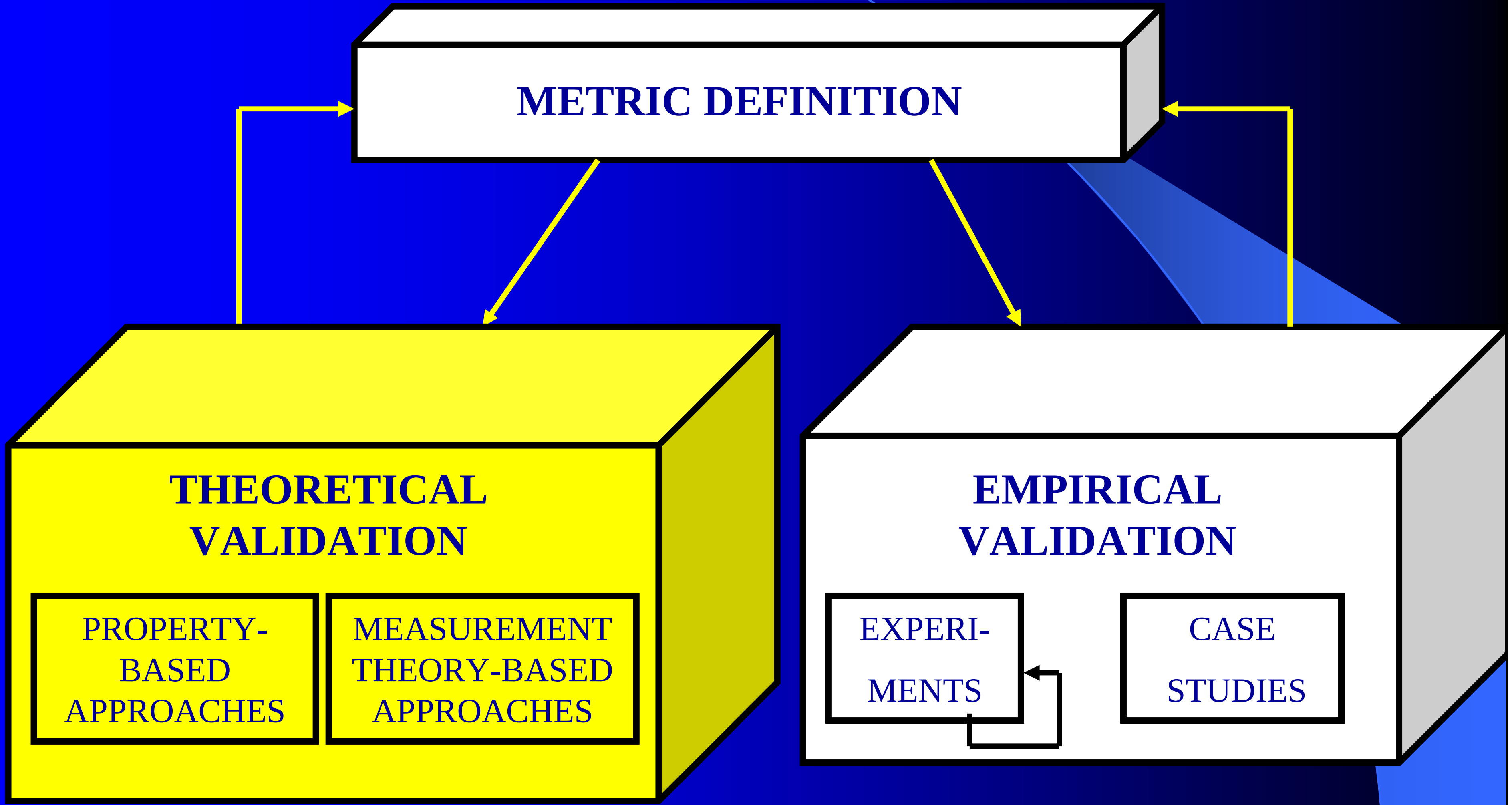
THEORETICAL VALIDATION



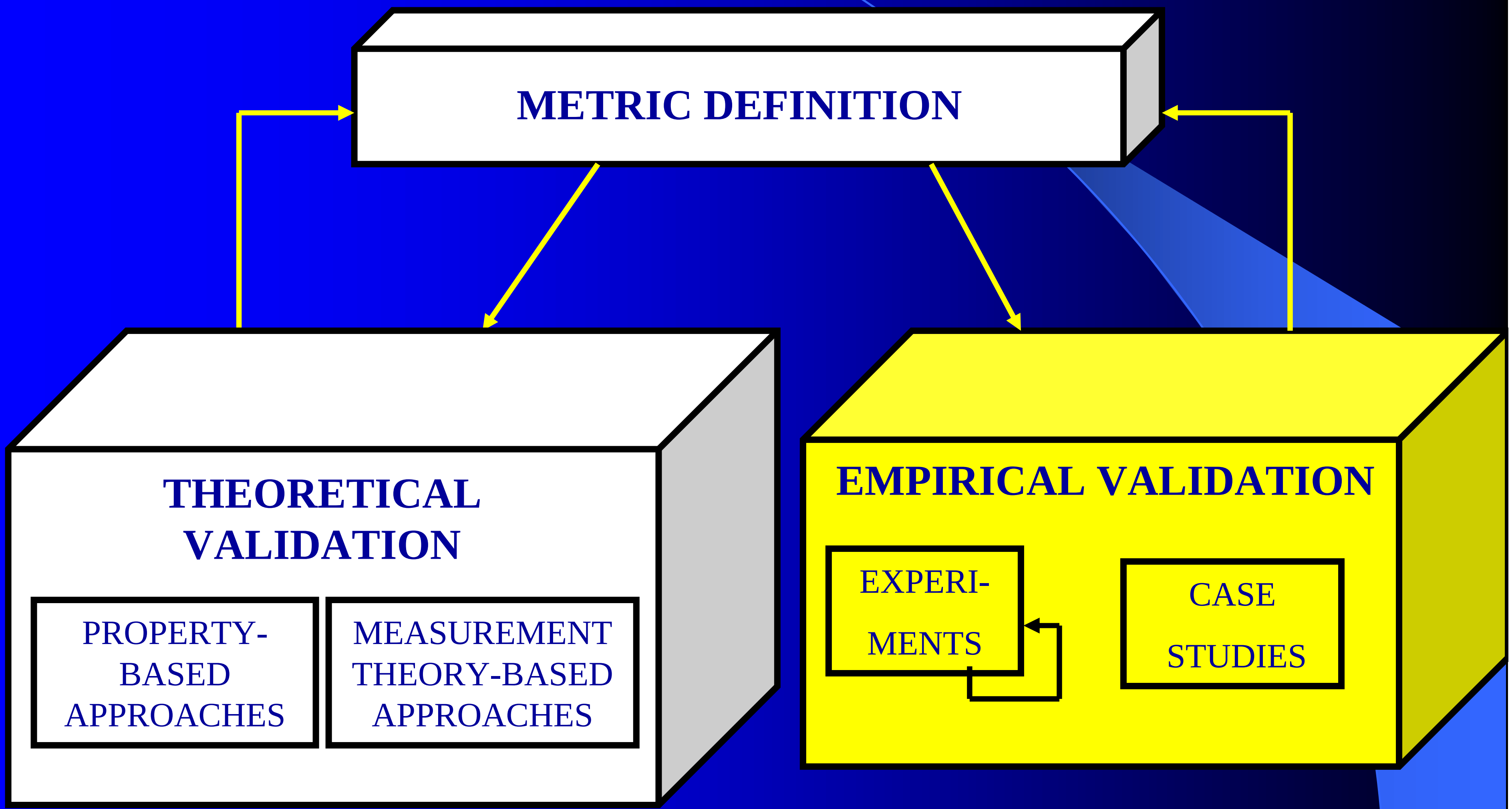
THEORETICAL VALIDATION: Metrics for ER diagrams

	NE, NA, NDA, NCA, NMVA	NR, NM:NR, N1:NR, NBinaryR, NN-ARYR, NIS_AR, NRefR, NRR
BRIAND ET AL.´S FRAMEWORK (1996)	Size	Complexity
ZUSE´S FRAMEWORK (1998)	Ratio	
POELS AND DEDENE´S FRAMEWORK (1999)	Ratio	

THEORETICAL VALIDATION: Class diagrams metrics

	CLASS DIAGRAMS-SCOPE METRICS		CLASS-SCOPE METRICS		
	NAggH, NGenH	NAssoc, NDep, NAgg, NGen	NDP, NP, NW	NAssocC, NDepIn, NDepOut	HAgg
BRIAND ET AL.´S FRAMEWORK(1996)	Size	Complexity	Size	Coupling	Length
POELS AND DEDENE´S FRAMEWORK (1999)	Ratio		Ratio		

EMPIRICAL VALIDATION



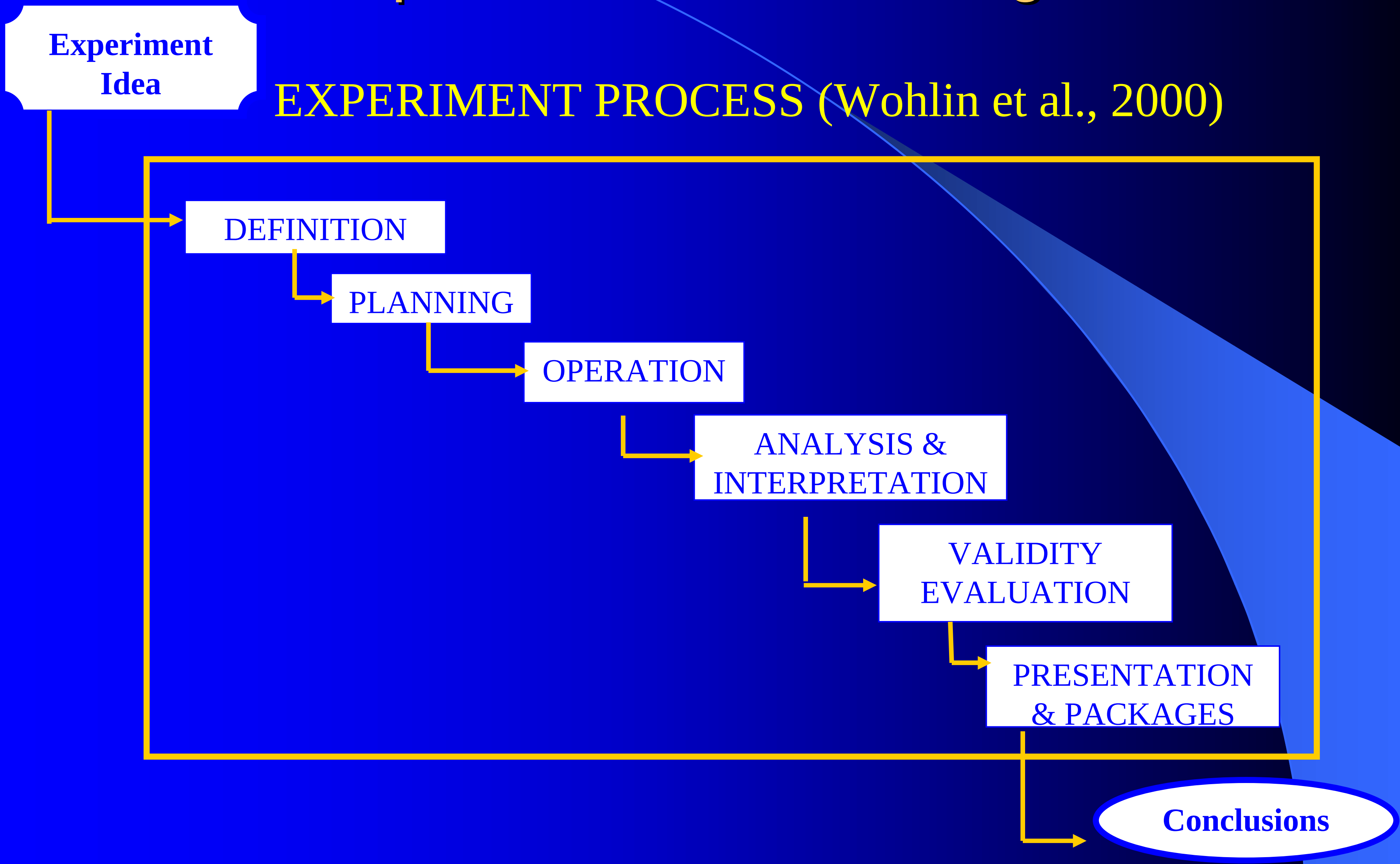
EMPIRICAL VALIDATION: Metrics for ER diagrams

Empirical studies	Considered metrics	Metrics partially validated	Subjects
FIRST EXPERIMENT	NE, NA, NR, NM:NR, N1:NR, NN-AryR, NBinaryR, NIS_AR	NE, NA, N1:NR, NBinaryR, NIS_AR	Professors and Students
SECOND EXPERIMENT	NE, NA, NR, NM:NR, N1:NR, NBinaryR, NN-AryR, NRefR	NE, NA, NR, N1:NR, NM:NR, NBinaryR, NN-AryR, NRefR	Students
THIRD EXPERIMENT	NE, NA, NR, NM:NR, N1:NR, NBinaryR	NE, NA, NR, N1:NR, NM:NR, NBinaryR	Students
CASE STUDY	NE, NA, NR, NM:NR, N1:NR, NBinaryR	NE, NA, NR, NM:NR, N1:NR, NBinaryR	Practitioners

EMPIRICAL VALIDATION: Class diagram-scope metrics

Empirical studies	Considered metrics	Metrics partially validated	Subjects
FIRST EXPERIMENT	NC, NA, NM, NAssoc, NAgg, NDep, NGen, NAggH, NGenH, MaxHAgg, MaxDIT	NC, NA, NM, NAssoc, NAgg, NDep, NGen, NAggH, NGenH, MaxHAgg, MaxDIT	Professors and students
SECOND EXPERIMENT	NC, NA, NM, NAssoc, NAgg, NDep, NGen, NAggH, NGenH, MaxHAgg, MaxDIT	NC, NA, NM, NAssoc, NAgg, NDep, NGen, NAggH, NGenH, MaxHAgg, MaxDIT	Professors and students
SECOND EXPERIMENT (REPLICATION)	NC, NA, NM, NAssoc, NAgg, NDep, NGen, NAggH, NGenH, MaxHAgg, MaxDIT	NC, NA, NM, NAssoc, NAgg, NGen, NAggH, MaxHAgg	Students
THIRD EXPERIMENT	NC, NA, NM, NAssoc, NAgg, NDep, NGen, NAggH, NGenH, MaxHAgg, MaxDIT	NC, NA, NM, NAssoc, NAgg, NDep, NGen, NAggH, NGenH, MaxHAgg, MaxDIT	Students

EMPIRICAL VALIDATION: An experiment for class diagrams



EMPIRICAL VALIDATION: An experiment for class diagrams

<u>1. DEFINITION</u>

Analyse	*UML class diagrams complexity metrics*
For the purpose of	*Evaluating*
With respect to	*The capability to be used as early quality indicators*
From the point of view of	*OOIS designers*
In the context of	*Undergraduate students and professors of the Software Engineering Area in the Department of Computer Science in the UCLM*

EMPIRICAL VALIDATION: An experiment for class diagrams

2. PLANNING

Context selection

- The experiment run off-line (not industrial software development)
- The subjects were 10 professors and 20 students enrolled in the final-year of Computer Science at the Department of Computer Science at the UCLM

Selection of subjects

- The subjects are chosen for convenience

EMPIRICAL VALIDATION:
An experiment for class diagrams

Variables selection

- The **independent variable** is the UML class diagram structural complexity
- The **dependent variable** is the UML class diagram maintainability

Instrumentation

- The objects were UML class diagrams
- The independent variable was measured through the metrics
- The dependent variable was measured by the time spent doing the experiment, the “maintenance time”

EMPIRICAL VALIDATION: An experiment for class diagrams

Hypotheses formulation

- Null hypothesis, H_0: There is not a significant correlation between the structural complexity metrics we proposed and the maintenance time
- Alternative hypothesis, H_1: There is a significant correlation between the structural complexity metrics we proposed and the maintenance time

Experiment design

- A within-subject design

EMPIRICAL VALIDATION: An experiment for class diagrams

3. OPERATION

Preparation

- The material consists of nine UML class diagrams of different application domains

- The diagrams have different complexity, considering a broad range of metrics values

- Each subject has to modify the class diagrams according to the new requirements and to write down the time spent in performing those modifications ("maintenance time")

EMPIRICAL VALIDATION: An experiment for class diagrams

Execution

- The subjects were given all the material.
- We explained to them how to carry out the experiment
- We allowed one week to do the experiment
- We collected all the empirical data

Data Validation

- We checked if the tests were complete and if the modifications were done correctly
- We discarded the test of seven subjects, because they included a required modification that was done incorrectly

EMPIRICAL VALIDATION: An experiment for class diagrams

<u>4. ANALYSIS AND INTERPRETATION</u>

Our goal is to ascertain if any correlation exists between each of the proposed metrics and the maintenance time

For analysing the empirical data we used three techniques:

- Statistical techniques
- Fuzzy classification and regression trees (Linares et al., 1996)
- Fuzzy prototypical knowledge discovery (Olivas, 2000)

EMPIRICAL VALIDATION: An experiment for class diagrams

5. VALIDITY EVALUATION

Threats to conclusion validity

- The only issue that could affect the statistical validity of this study are the size of the sample data (243 values, 9 diagrams and 27 subjects)

Threats to construct validity

- The dependent variable we used is the maintenance time, so we consider this variable constructively valid

- The construct validity of the measures used for the independent variables is guaranteed by Poels and Dedene´s framework (Poels and Dedene, 1999; 2000a) used to validate them

EMPIRICAL VALIDATION: An experiment for class diagrams

Threats to internal validity

- Differences among subjects
- Knowledge of the universe of discourse
- Precision in time values
- Learning effects
- Fatigue effects
- Persistence effects
- Subject motivation
- Other factors

Threats to external validity

- Materials and tasks used
- Subjects

EMPIRICAL VALIDATION: An experiment for class diagrams

6. PRESENTATION & PACKAGES

- We have published the results of this experiment in a paper presented in the SCCC 2001 Conference
- We have also put all of the material of this experiment on the web http:\\alarcos.inf-cr.uclm.es

EMPIRICAL VALIDATION:
An experiment for class diagrams

EXPERIMENT CONCLUSIONS

- NC, NA, NM, NAssoc, NAgg, NDep, NGen, NAggH, NGenH, MaxHAgg, MaxDIT are to some extent correlated with maintenance time

	NC	NA	NM	NAssoc	NAgg	NDep	NGen	NAggH	NGenH	MaxHAgg	Max DIT
Maintenance Time	1	1	0,828	0,557	0,547	0,411	0,575	0,675	0,696	0,555	0,719

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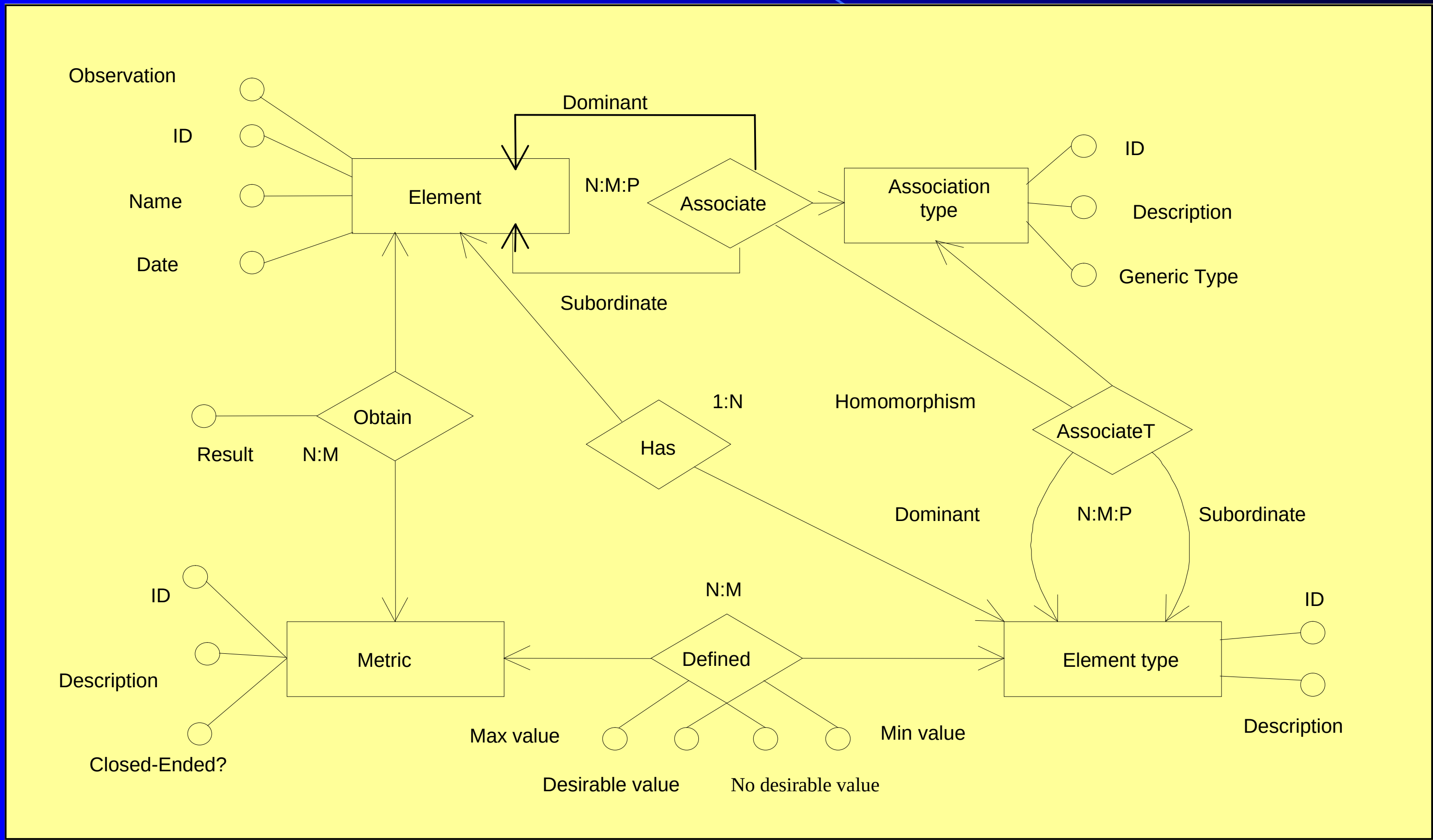
MANTICA Tool



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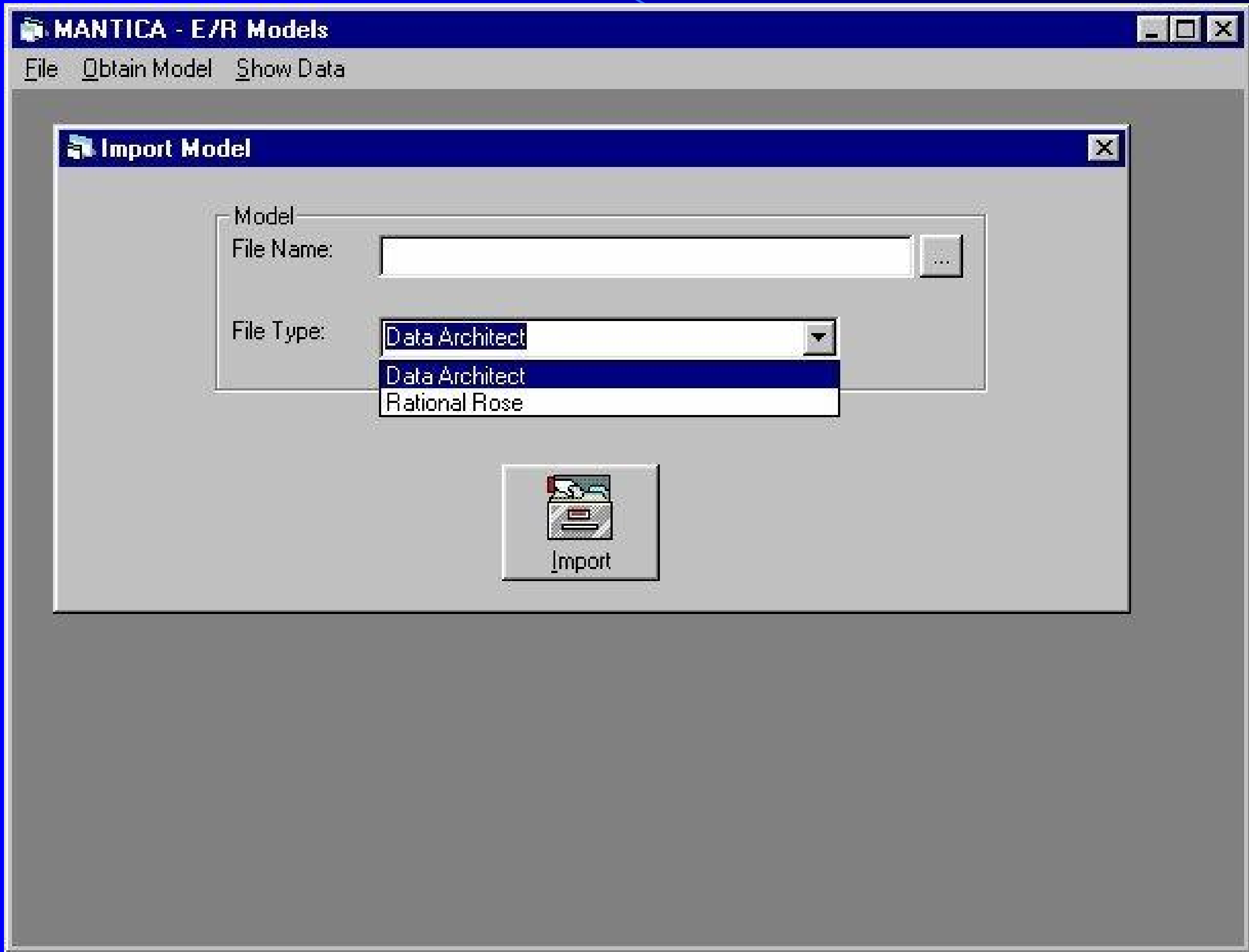

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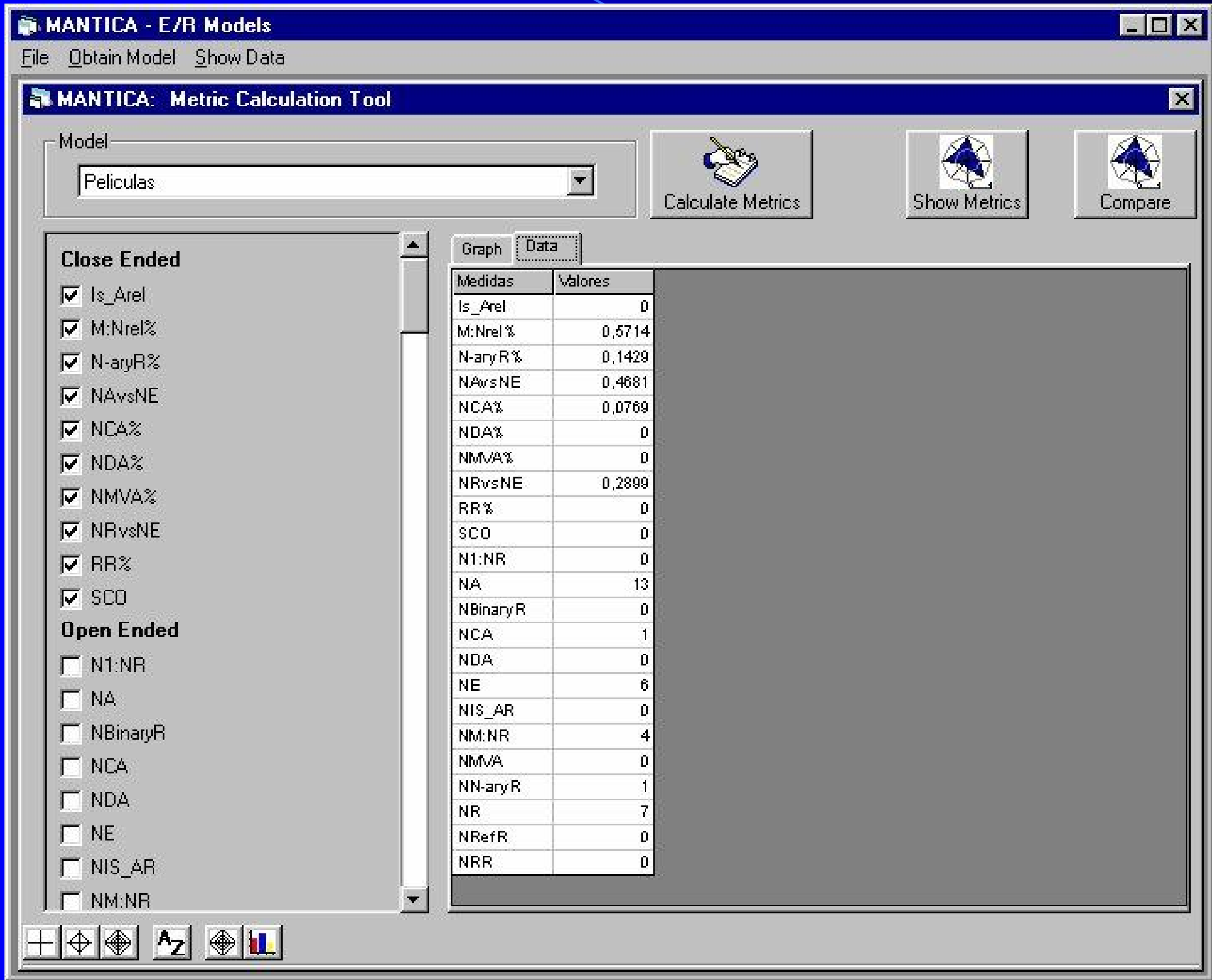

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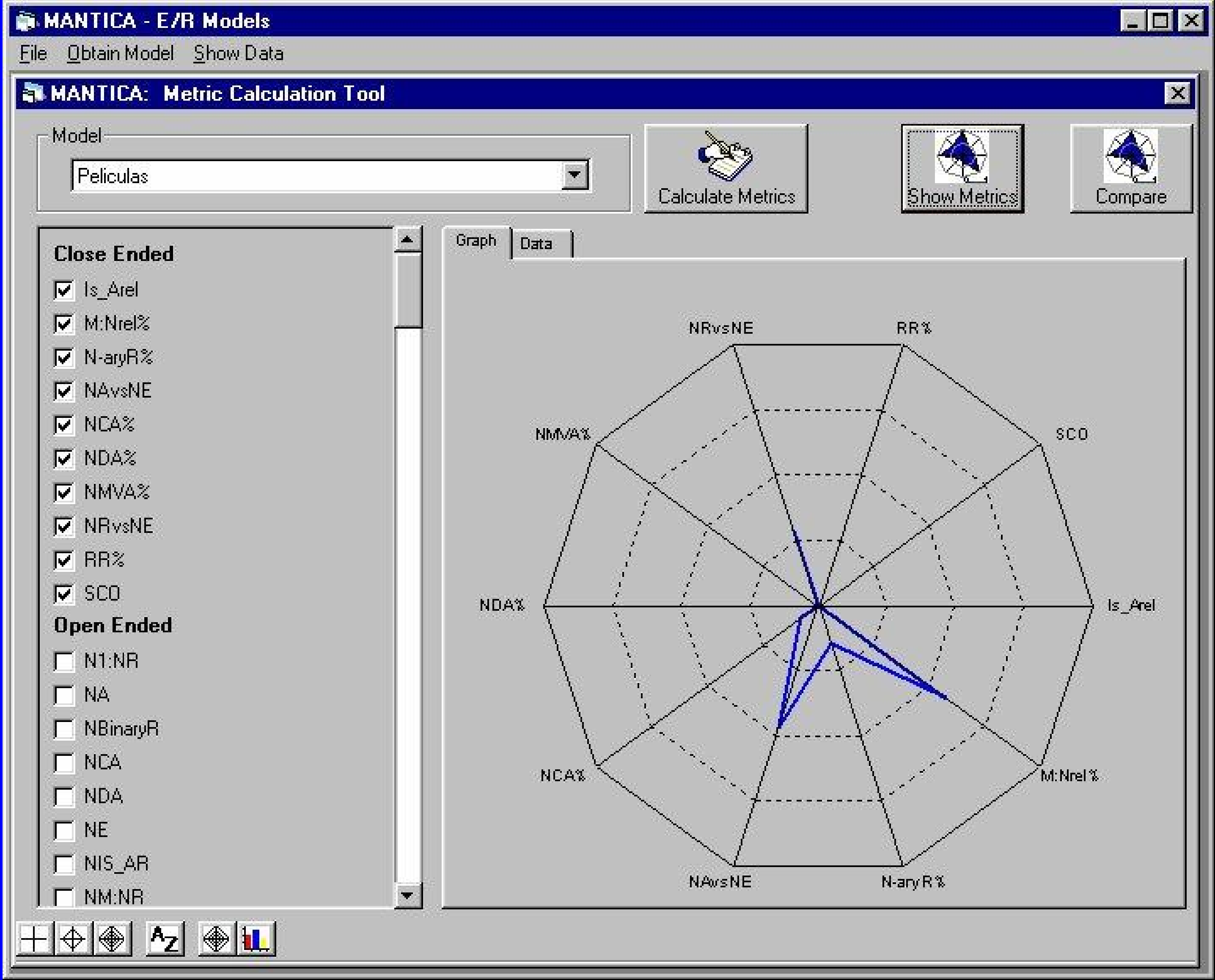

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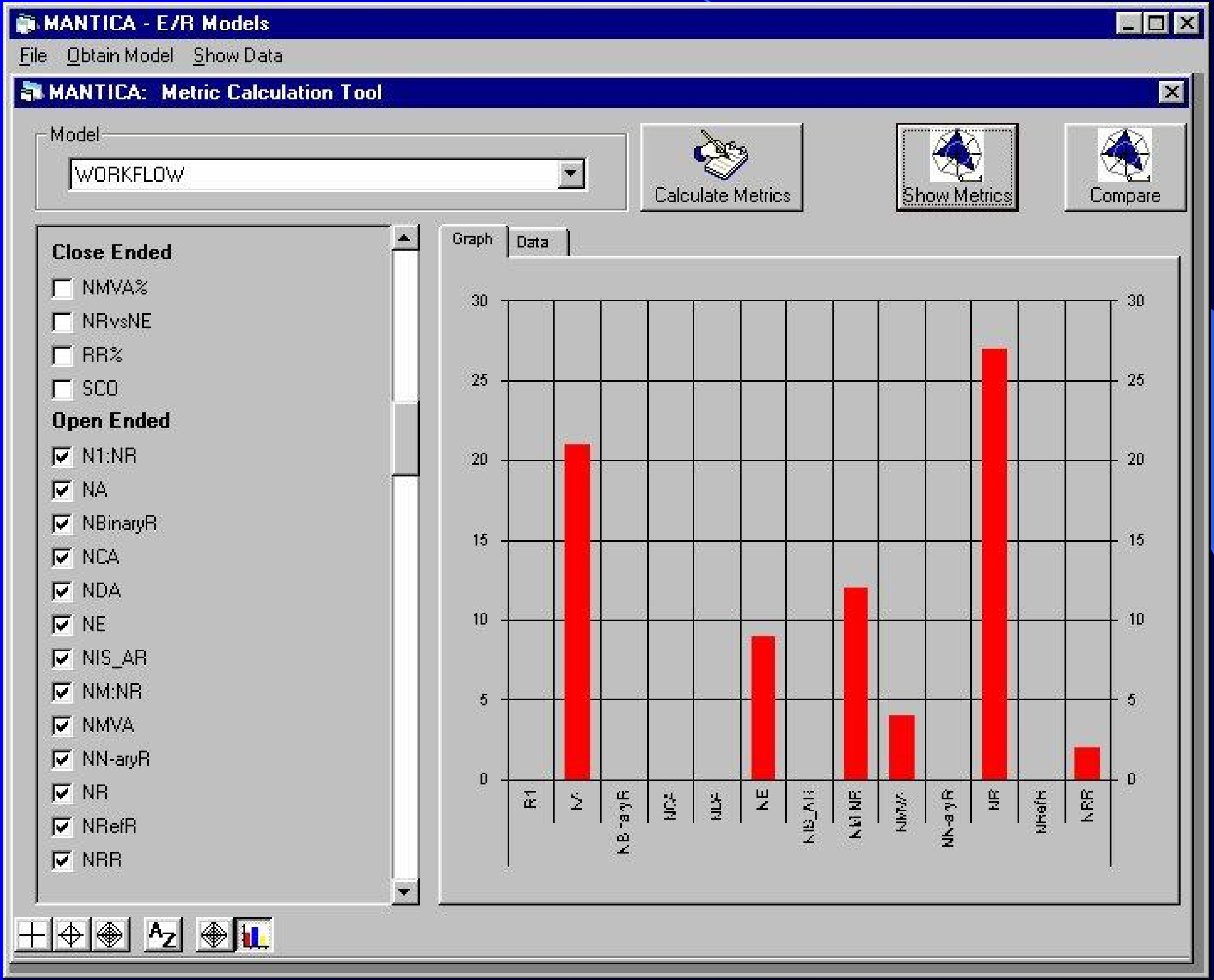


CONTENTS

- Introduction
- Research Method
- State of the Art
- Metric Definition
- Metric Validation
- MANTICA Tool
- **Conclusions**
- Future work

CONCLUSIONS:
Analysis of achievement of objectives

1. Analyse the existing metrics
2. Define a method for the definition of valid metrics
3. Define a set of metrics
4. Study formal measurement frameworks
5. Perform the theoretical validation
6. Study the different empirical strategies
7. Perform the empirical validation
8. Design and develop a tool prototype

CONCLUSIONS:
Analysis of achievement of objectives

MAIN OBJECTIVE

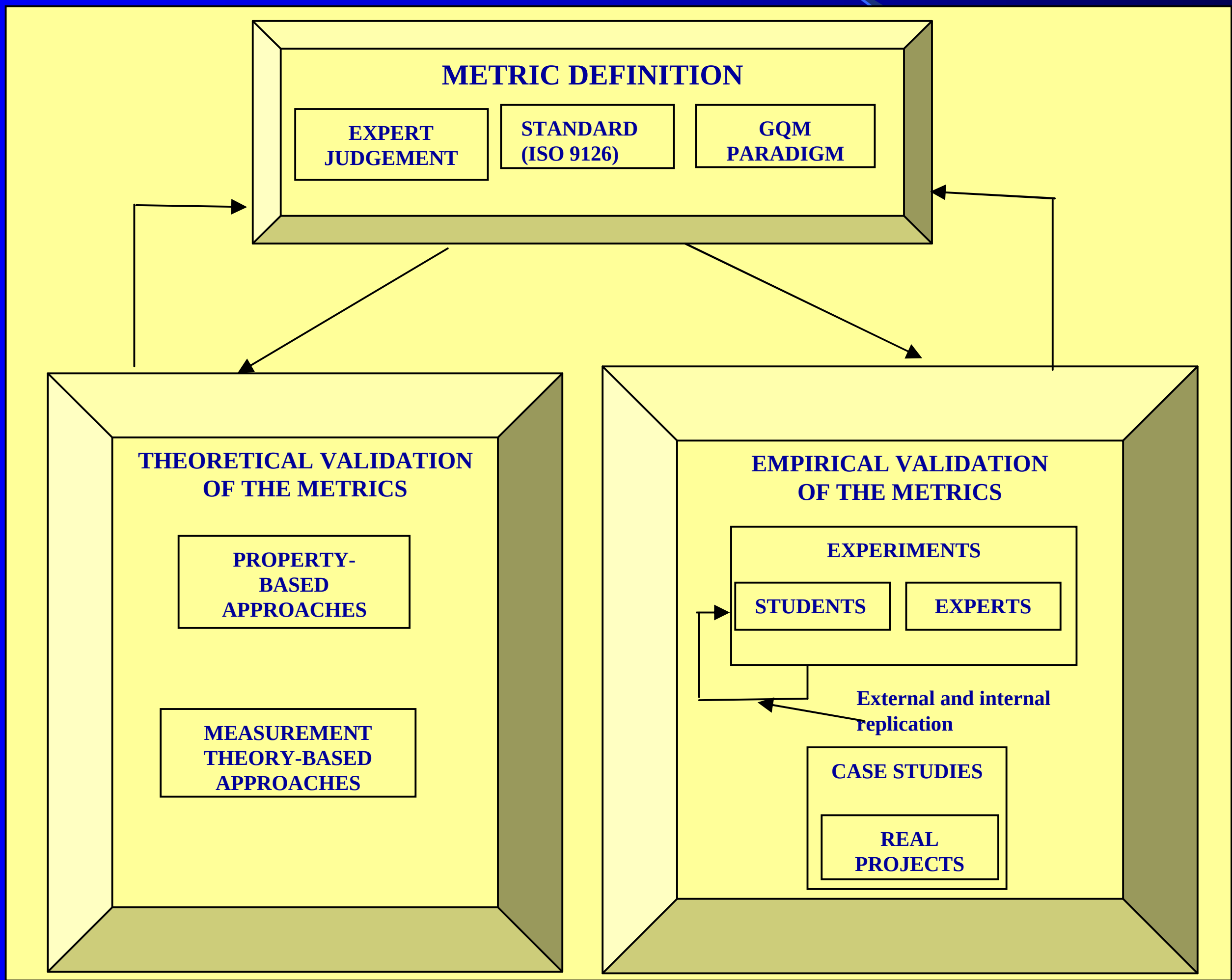
DEFINE A SET OF METRICS TO ASSESS AND CONTROL THE MAINTAINABILITY OF TRADITIONAL AND OO CONCEPTUAL MODELS

CONCLUSIONS:
Corroboration of the hypothesis

IT IS FEASIBLE TO DEFINE METRICS TO ASSESS AND CONTROL THE MAINTAINABILITY OF TRADITIONAL AND OO CONCEPTUAL MODELS

CONCLUSIONS: Contributions

- Method for metric definition



CONCLUSIONS: Contributions

- VALID metrics for the structural complexity of:
  - ER diagrams
  - Class diagrams
    - Class diagram-scope
    - Class-scope
- MANTICA Tool

CONCLUSIONS: Contrast of Results

INTERNATIONAL JOURNALS

- Genero M., Piattini M. and Calero C. (2000). Early Measures For UML class diagrams. ***L´Objet***. 6(4), Hermes Science Publications, 489-515
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CONCLUSIONS: Contrast of Results

BOOK CHAPTERS

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CONCLUSIONS: Contrast of Results

BOOK CHAPTERS

- Piattini M., Genero M. and Calero C. (2001). Data Models Metrics. *In: **SEKE Handbook** VOL. II*. (to appear)
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CONCLUSIONS: Contrast of Results

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CONCLUSIONS: Contrast of Results

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CONCLUSIONS: Contrast of Results

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CONCLUSIONS: Contrast of Results

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- Genero M., Jiménez, L. and Piattini M. (2001). Empirical Validation of Class Diagram Complexity Metrics. ***SCCC 2001***, November, Chile, IEEE Computer Society Press, 95-104
- Genero M., Piattini M. and Calero M. (2001). Assurance of Conceptual Data Model Quality Based on Early Measures. ***APAQS 2001***, December, Hong Kong, IEEE Computer Society Press, 97-103
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CONCLUSIONS: Contrast of Results

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CONTENTS

- Introduction
- Research Method
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- Metric Definition
- Metric Validation
- MANTICA Tool
- Conclusions
- **Future work**

FUTURE WORK

- **Related to the metric definition method**
  - Psychological Explanation
  - Definition of Threshold Values
- **Related to the definition of metrics**
  - Metrics for ER diagrams and class diagrams
  - Metrics for use case diagrams
  - Metrics for dynamic aspects of OO models
  - Metrics for patterns
  - Metrics for the conceptual modelling process

FUTURE WORK

- **Related to the theoretical validation**
- **Related to the empirical validation**
- **Related to a software measurement process**
- **Related to prediction models**

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DEFINING AND VALIDATING METRICS FOR CONCEPTUAL MODELS

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