



Ubiquitous Computing Laboratory
Kyung Hee University, Korea

PhD Dissertation Presentation



Efficient Semantic Reconciliation for Data Interoperability among Heterogeneous Health-care Systems

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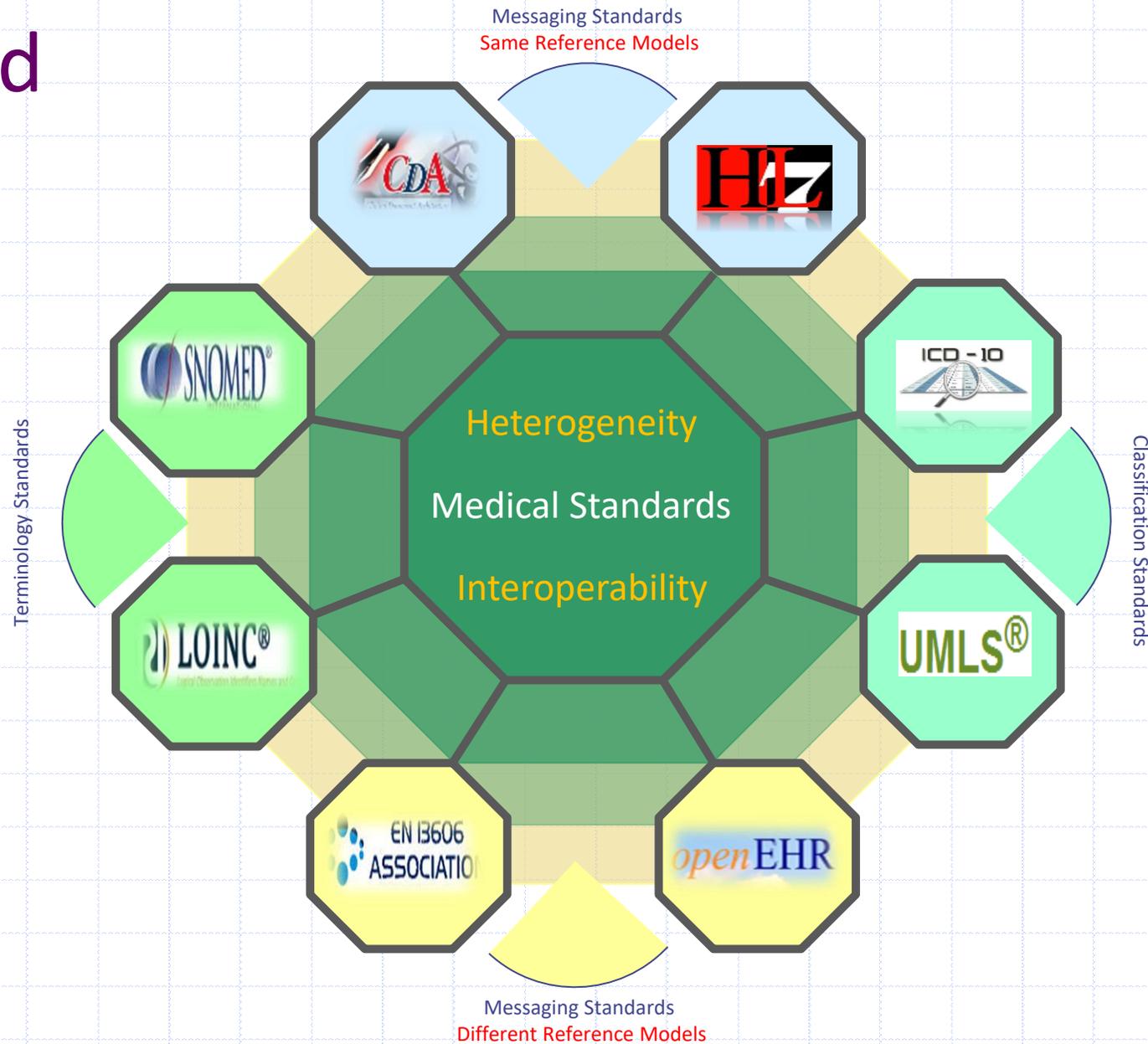
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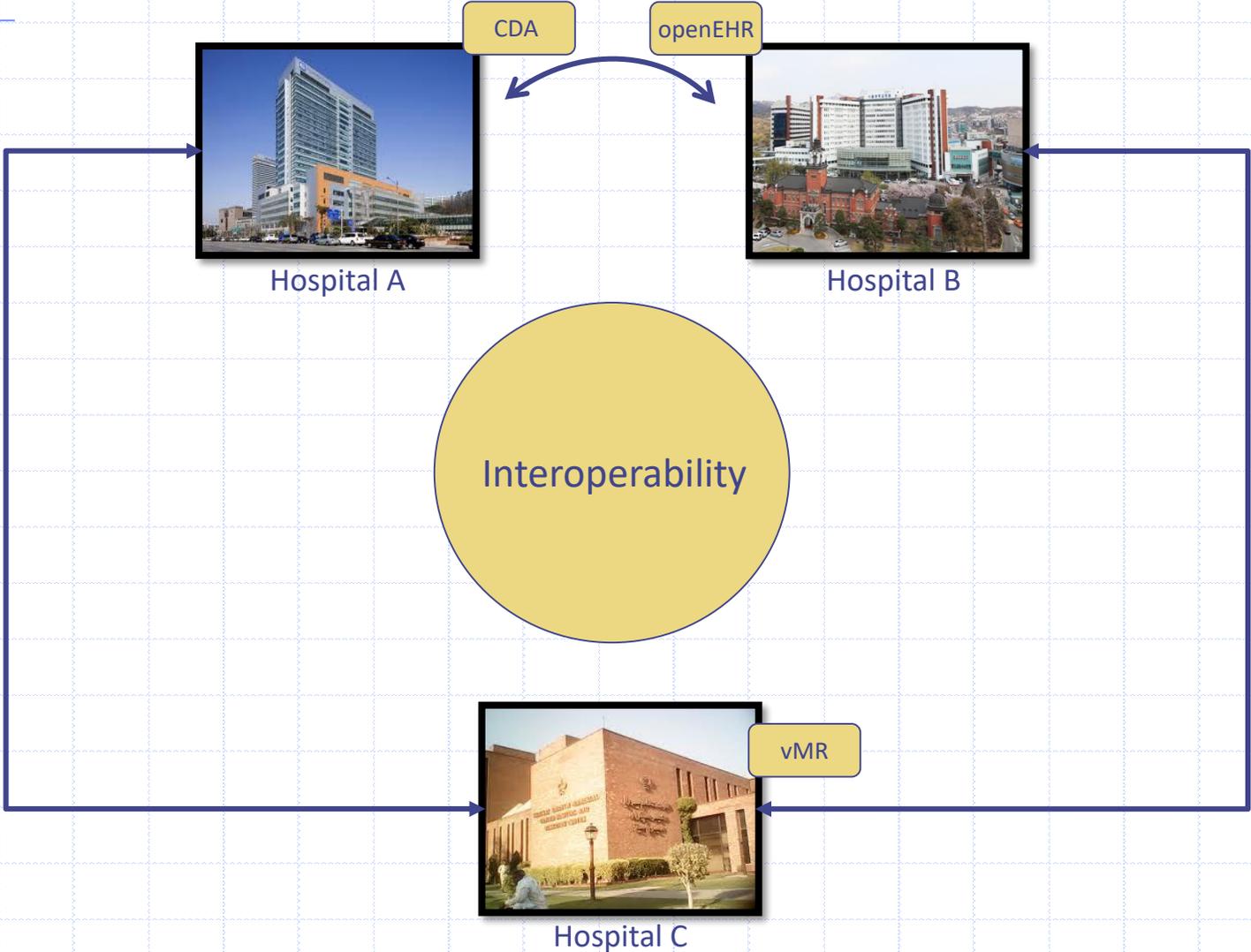
Contents

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 - Background
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Background



Motivation



Problem Statement

- ◆ Health-care systems compliant to heterogeneous standards possess semantic heterogeneity
- ◆ These systems are unable to effectively communicate due to non interoperable approaches
- ◆ These approaches exist because of lack of semantic reconciliations applicability

Goals

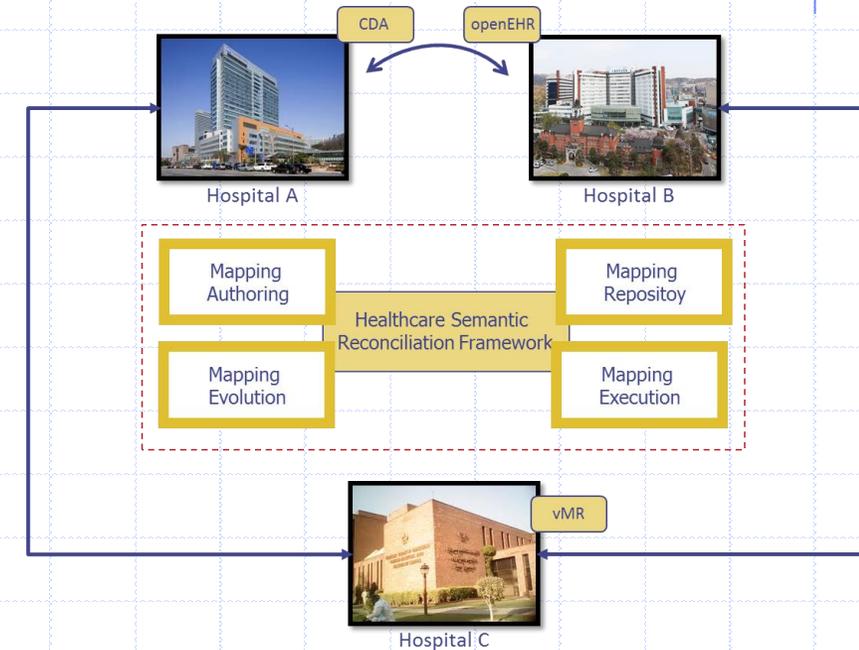
- ◆ accurate generalized mappings, customized mappings, effective mapping representation, standard formats transformation

Challenges

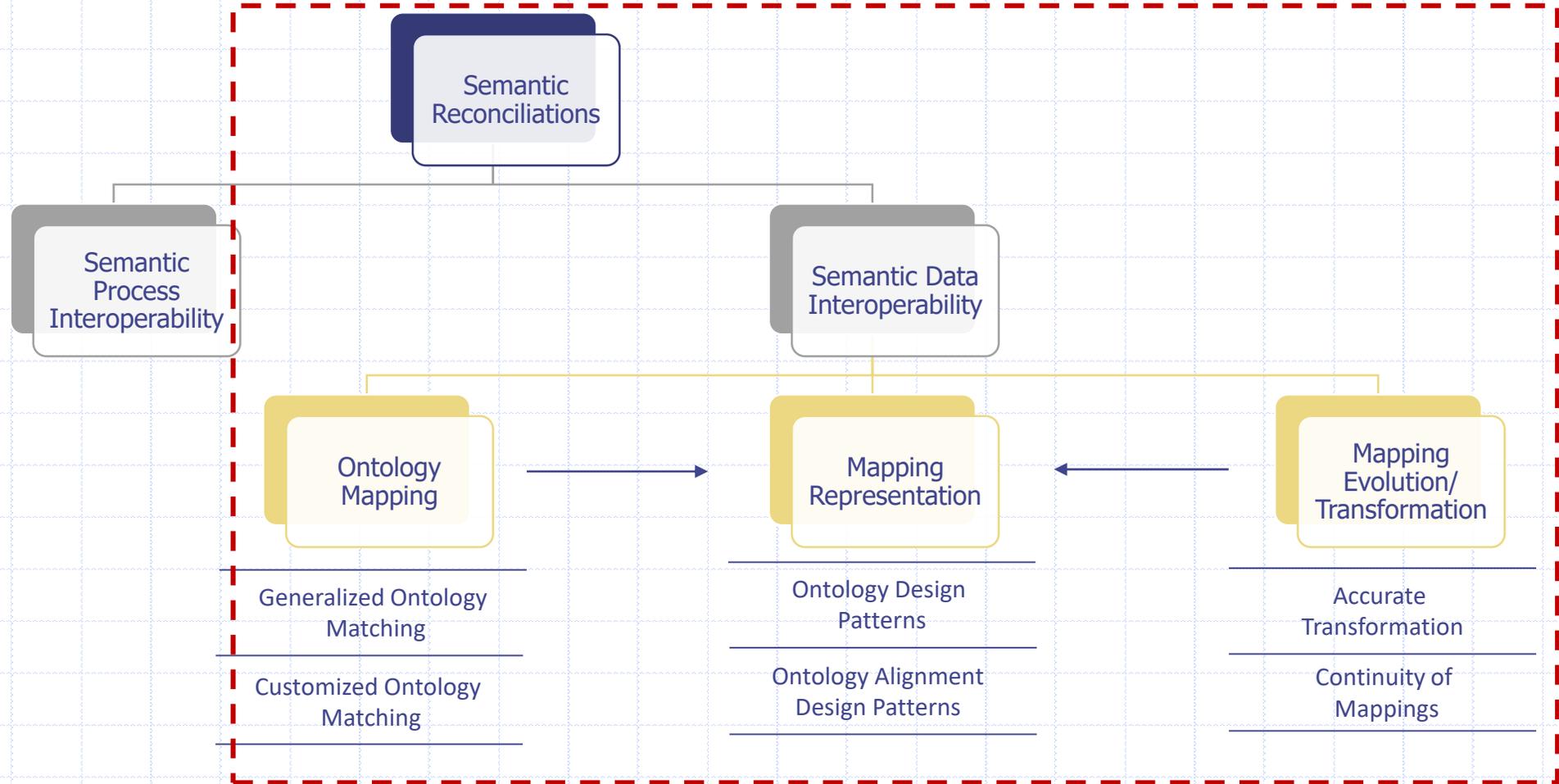
How to maintain higher accuracy in generation and transformation of mappings between heterogeneous standards with integrated organization conformance information?

What design factors to take into consideration to effectively store, represent, and transform the generated mappings?

Solution

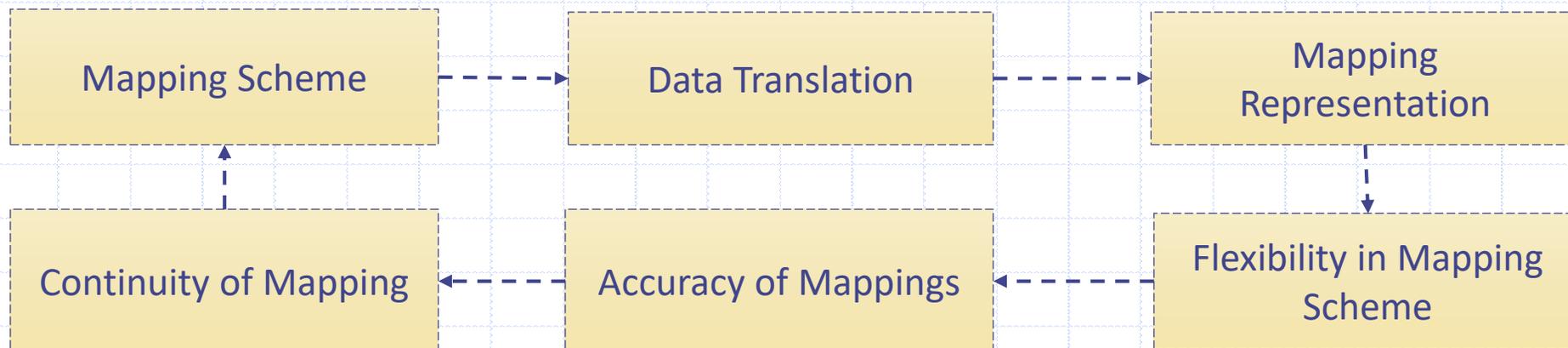


Research Taxonomy



Related Work

- ◆ Semantic based interoperability systems categories [5] [7] [19]
 - Focus on **Ontology Matching Techniques**
 - Focus on **Medical Ontologies Matching Systems**
 - Focus on **Data Translation Mechanism**
- ◆ Comprehensive semantic interoperability framework requirements [10] [14]



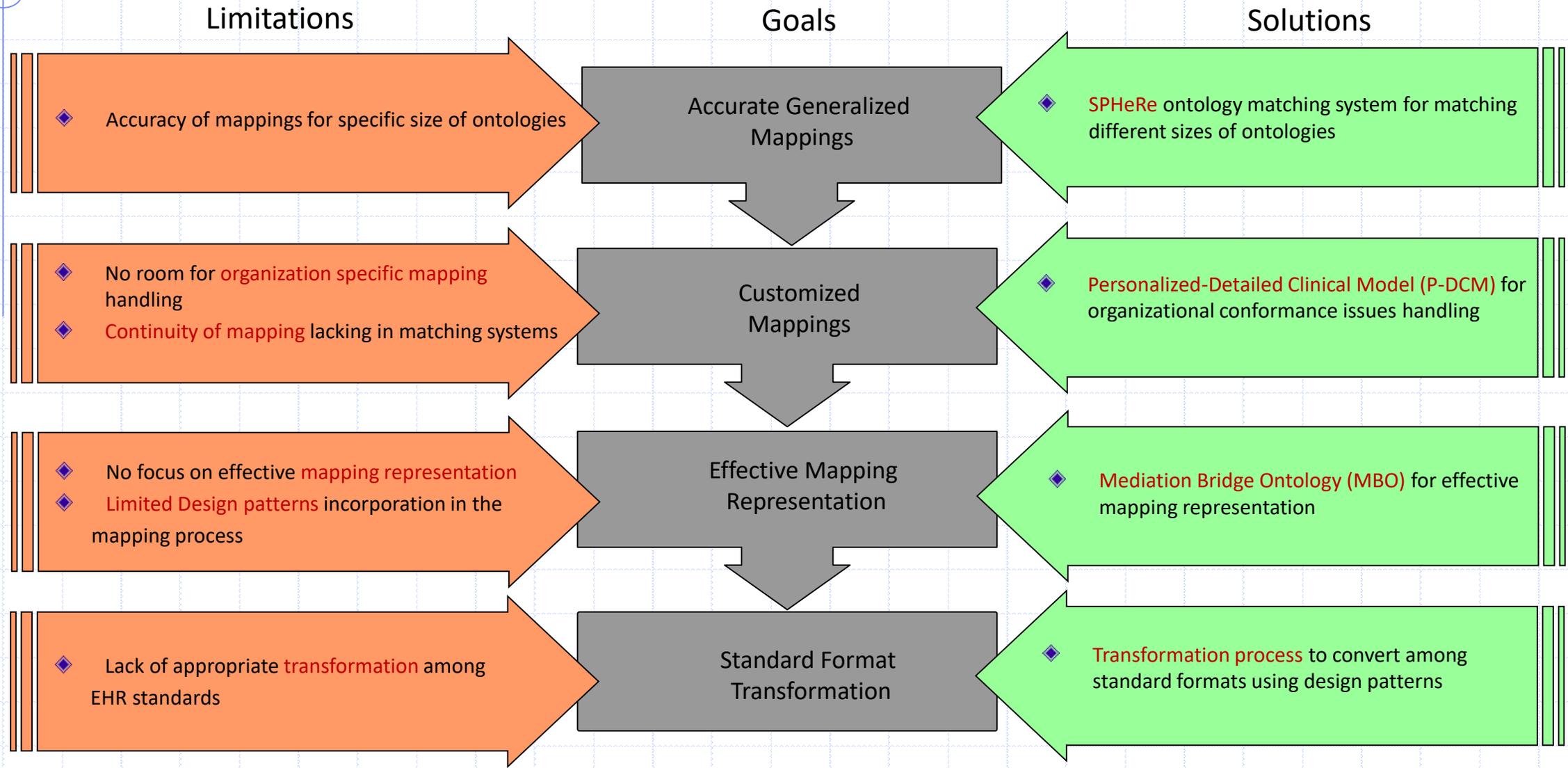
Related Work

Category	Systems	Mapping Scheme	Data Translation	Mapping Representation	Flexibility in Mapping Representation	Accuracy of Mapping	Continuity of Mapping
Ontology Matching Techniques	GOMMA [2] [19]	✓	✗	✓	✗	✓	✓
	LogMap [1] [5]	✓	✗	✓	✗	✓	✗
	Agreement Maker [4] [8]	✓	✗	✓	✗	✗	✗
	Falcon [3] [9]	✓	✗	✓	✗	✗	✗
Medical Ontologies Matching Systems	SAMBO [6] [17]	✓	✓	✓	✗	✗	✗
	ASMOV [15] [16]	✓	✓	✓	✗	✗	✗
Data Translation Mechanisms	LinkEHR [12] [13]	✓	✓	✓	✗	✗	✗
	PPEPR [7] [8]	✗	✓	✗	✗	✗	✗
	Proposed Approach	✓	✓	✓	✓	✓	✓

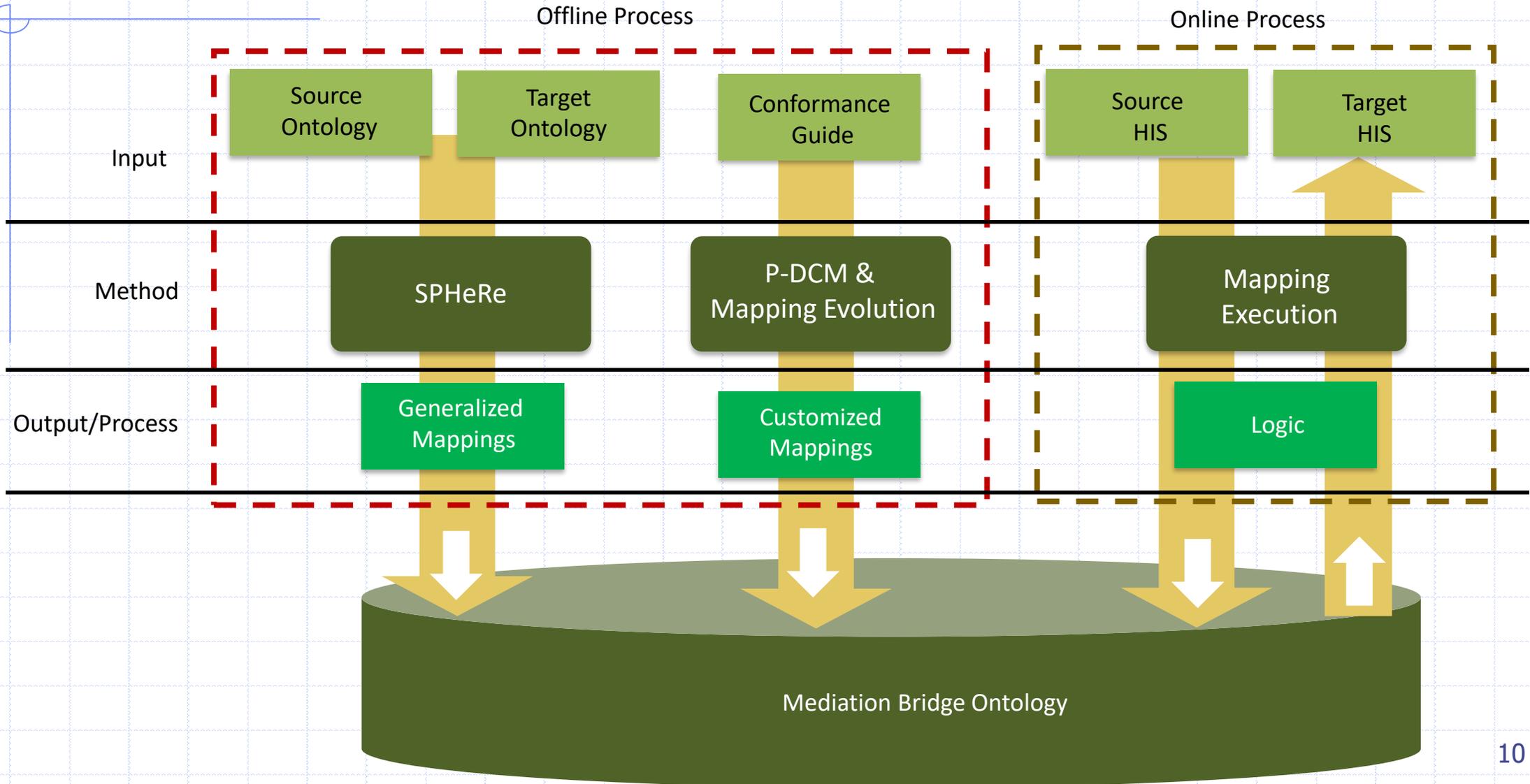
Limitations of Existing Systems

- ◆ No focus on effective **mapping representation**
- ◆ **Limited design patterns** incorporation in the mapping process
- ◆ No room for **organization specific mapping** handling
- ◆ **Accuracy of mapping** for specific size of ontologies
- ◆ Lack of appropriate **transformation** among EHR standards
- ◆ **Continuity of mapping** lacking in matching systems

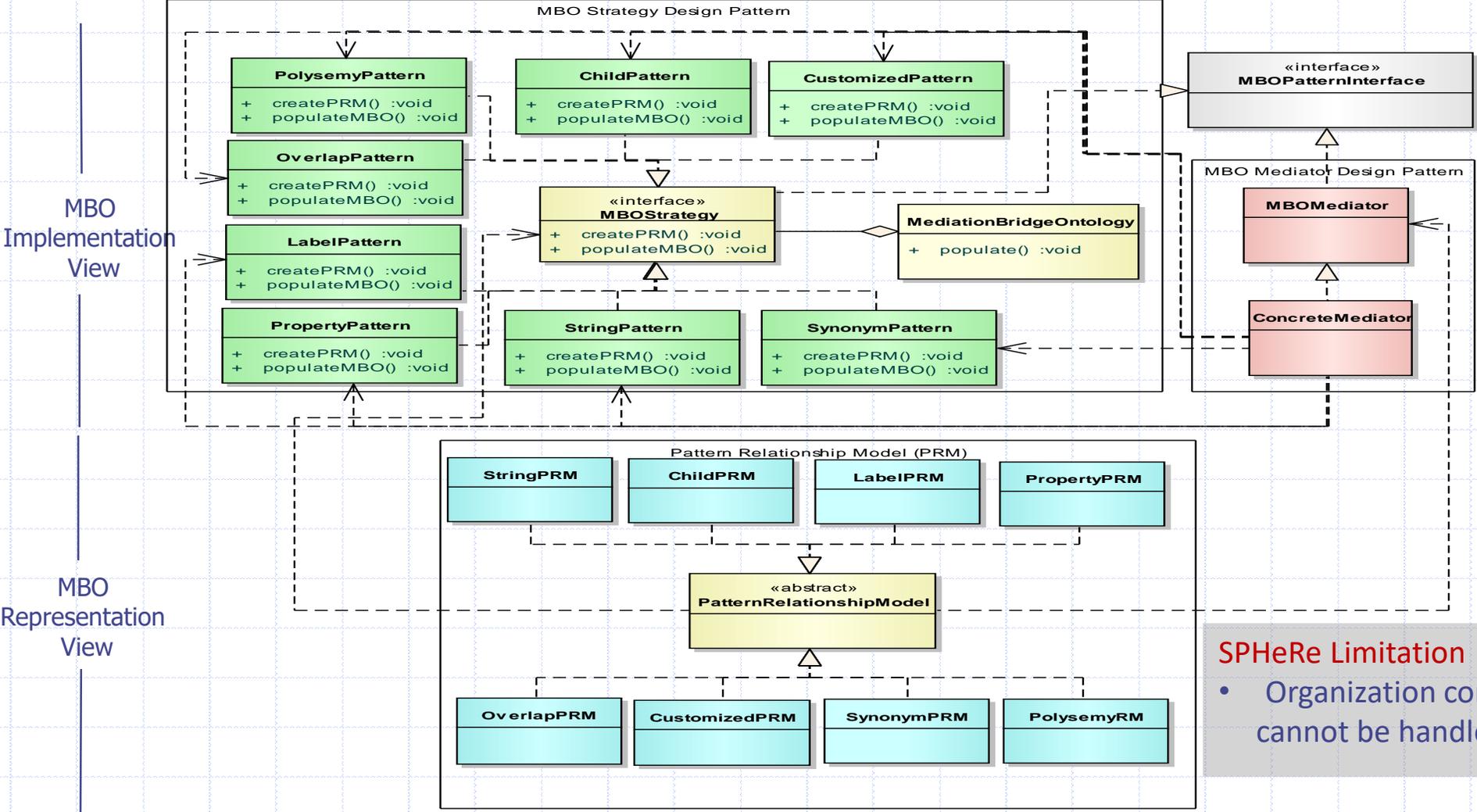
Proposed Methodology



Integrated Workflow



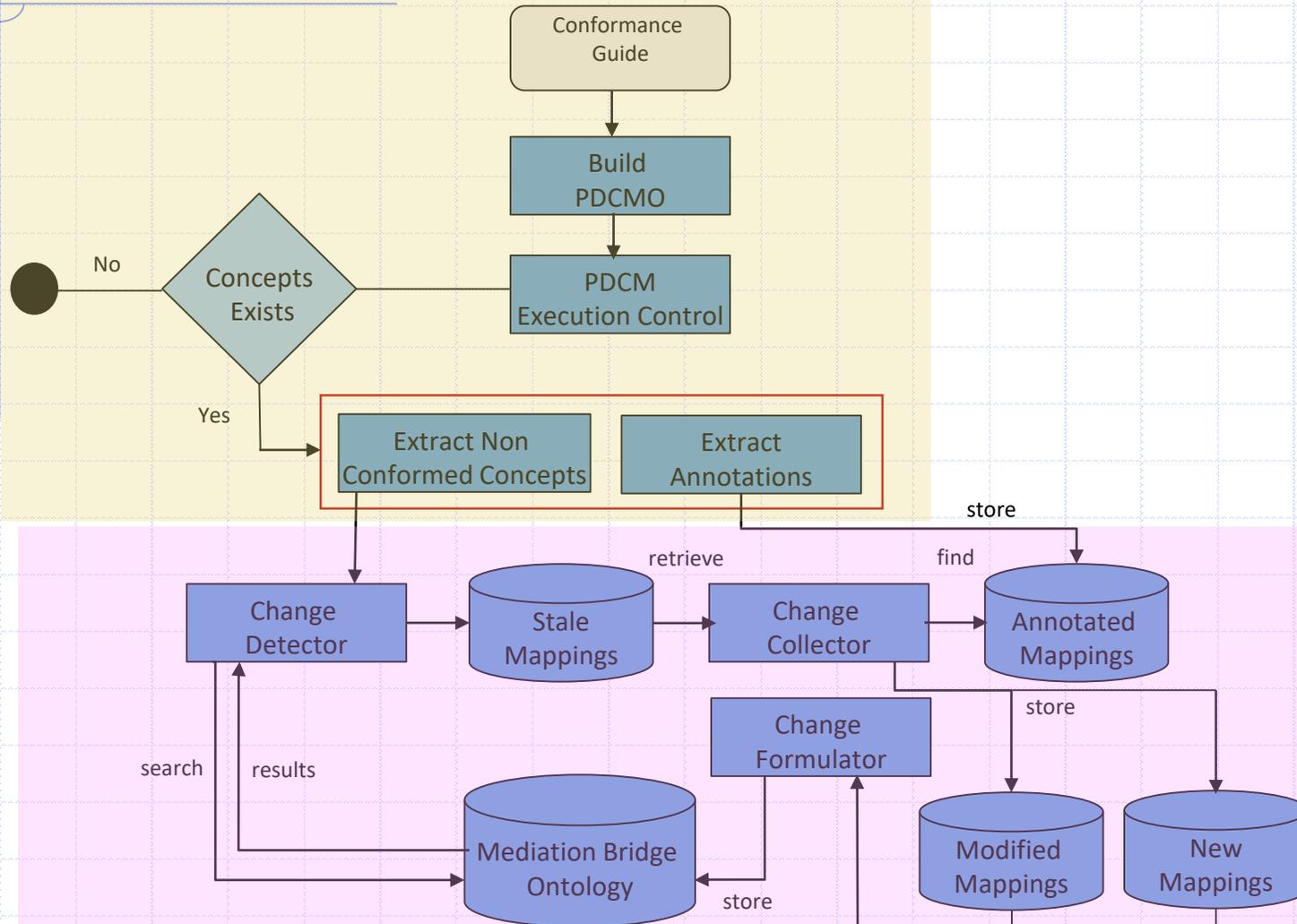
Solution 1: Object Oriented and Ontology Design Patterns



SPHeRe Limitation

- Organization conformance issues cannot be handled using SPHeRe

Solution 2: Personalized-Detailed Clinical Model (P-DCM) Approach

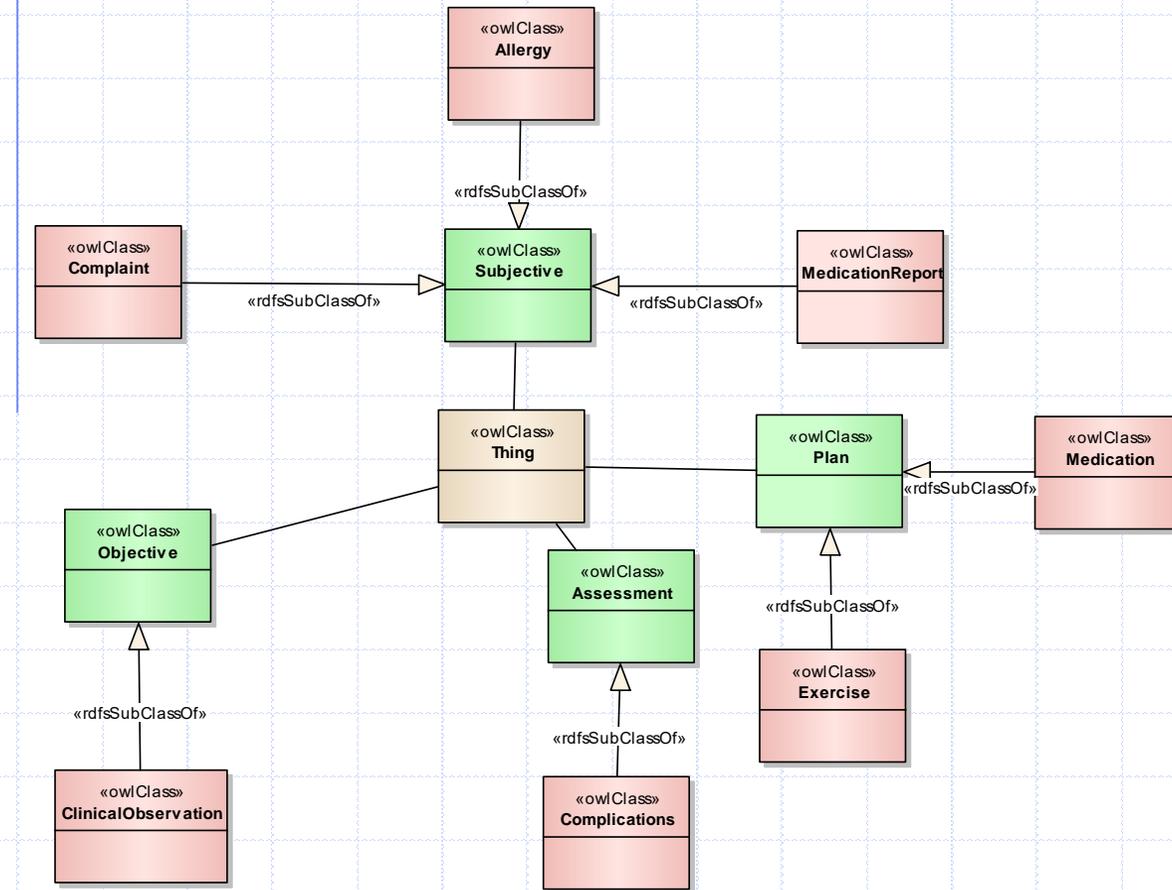


Existing Approaches Differences

- CIMI* handles DCM for aligning standards
- Generalized and customized mappings relationship

*Clinical Information Modelling Initiative

Solution 2: Personalized-Detailed Clinical Model (P-DCM) Approach

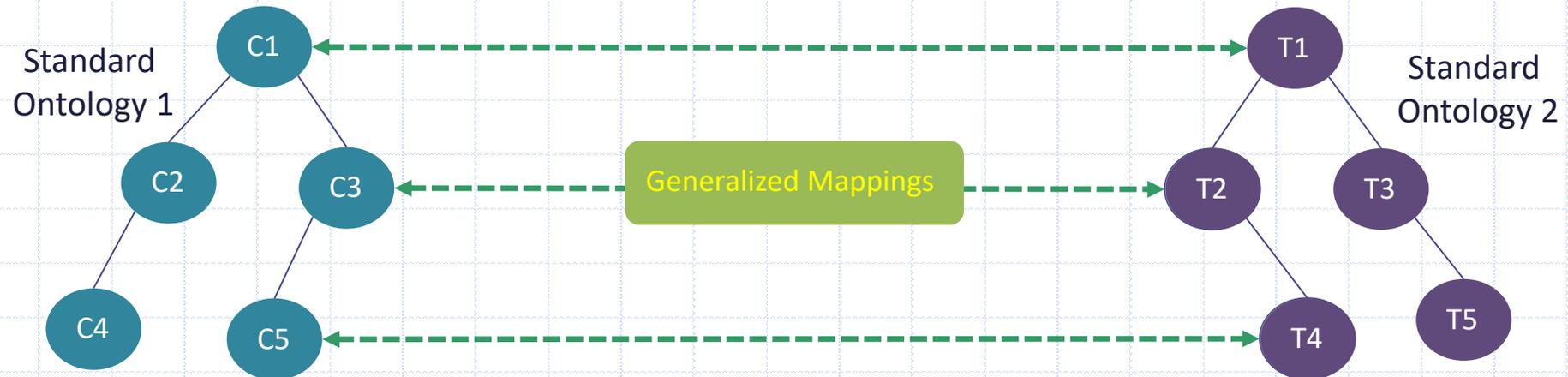
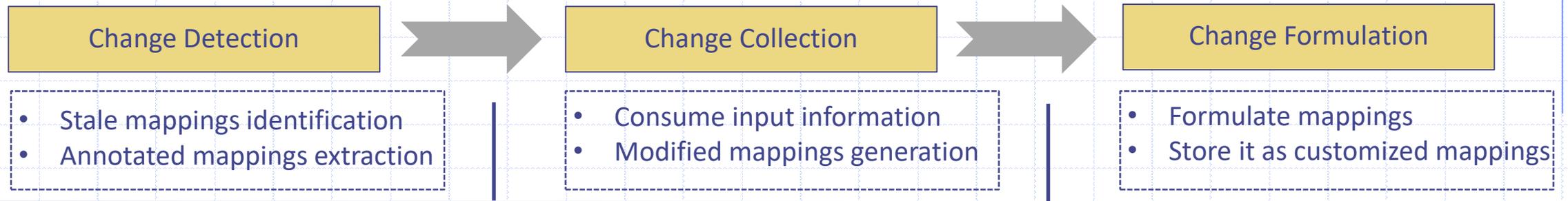


P-DCM Ontology

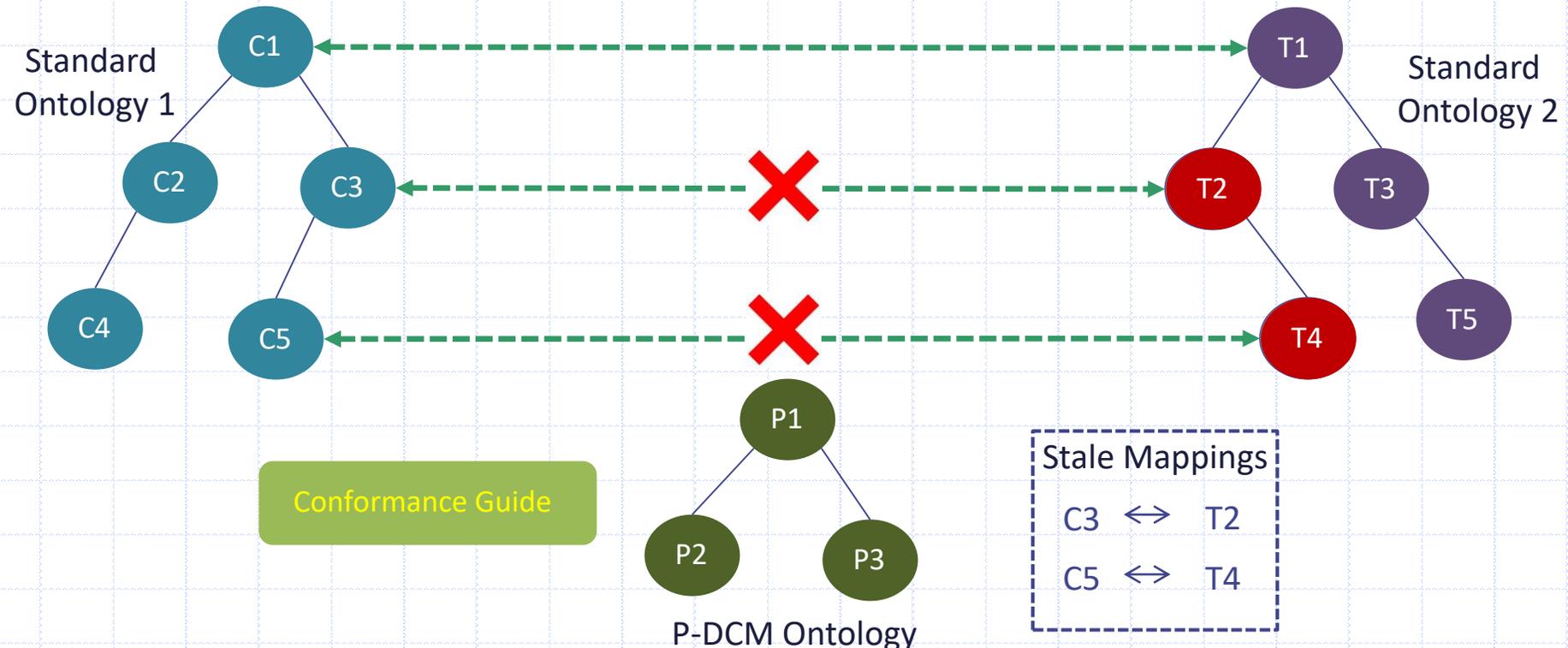
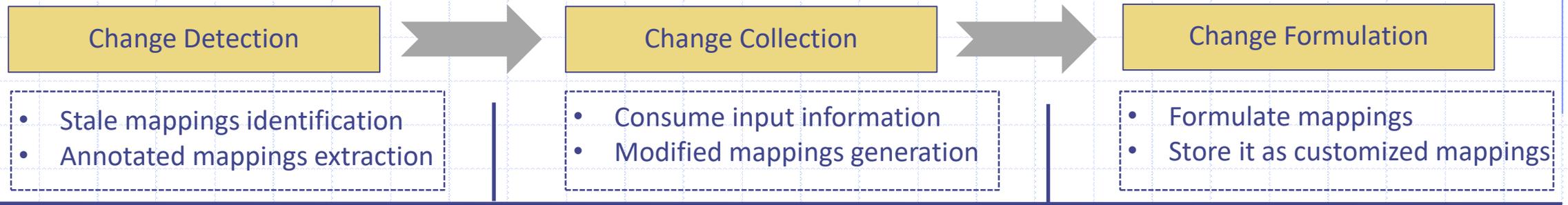
P-DCM Concept	Value	openEHR Class [Attribute]	HL7 Rim Core Class	HL7 Class [Attribute]
Assessment	Chronic Disease Assessment	Composition	Act	Organizer
Complication	Non Insulin Dependent Diabetes Mellitus	Section	Act	Observation
Objective	(objective)	Section	Act Relationship	Entry
Clinical Observation	Blood Pressure	Observation	Act	Observation

Standards Annotations [HL7 and openEHR]

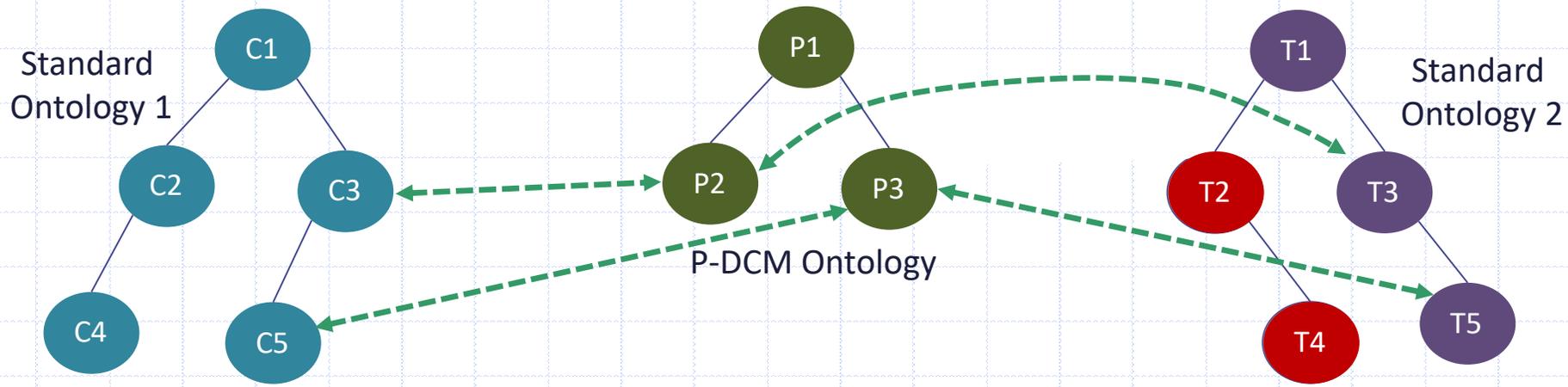
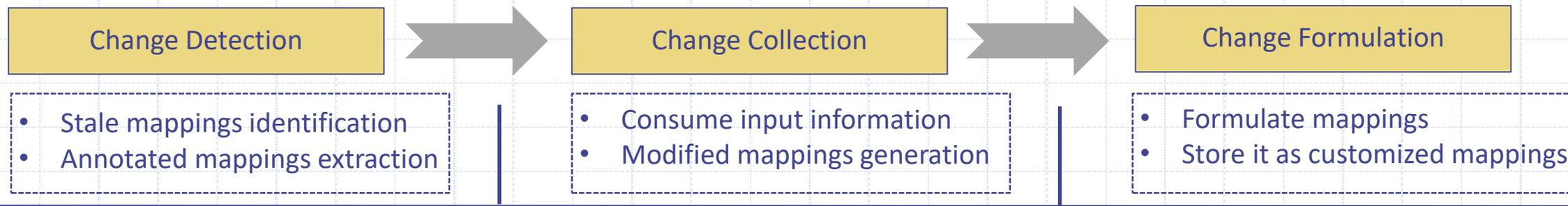
Solution 2: Mapping Evolution - Continuity of Mapping



Solution 2: Mapping Evolution - Continuity of Mapping



Solution 2: Mapping Evolution - Continuity of Mapping



SPHeRe and P-DCM Mappings Storage

- Requires expressive mapping storage mechanism for use in transformation and mapping evolution



Solution 3: Mediation Bridge Ontology (MBO) – Generalized Mappings

$\langle \text{MBO} \rangle ::=$ "Generalized Mappings : " $\langle \text{GM} \rangle$
 "Customized Mappings : " $\langle \text{CM} \rangle$
 "Transformation Logic : " $\langle \text{Logic} \rangle$

MBO Constructs

$\langle \text{GM} \rangle ::=$ "Alignment Info : " $\langle \text{AlignInfo} \rangle$
 "Pattern Relationship Model : " $\langle \text{PRM} \rangle$
 "Logic GM : " $\langle \text{LogicGM} \rangle$

Generalized Mappings Structure

$\langle \text{AlignInfo} \rangle ::=$ "Source Entity : " $\langle \text{SE} \rangle$
 "Target Entity : " $\langle \text{TE} \rangle$
 "Measure Threshold Value : " $\langle \text{MTV} \rangle$
 "Relationship : " $\langle \text{R} \rangle$

Alignments Structure

$\langle \text{SE} \rangle ::= \{x \mid O_1 \cap x \in \langle S_{\Delta}, x_i \rangle$
 $\langle S_{\Delta}, x_i \rangle ::= \{(x_i \in S_{\Delta}) \wedge (S_{\Delta} \in O_1)\}$
 $\langle \text{TE} \rangle ::= \{x \mid O_2 \cap x \in \langle T_{\Delta}, x_i \rangle$
 $\langle T_{\Delta}, x_i \rangle ::= \{(x_i \in T_{\Delta}) \wedge (T_{\Delta} \in O_2)\}$

Alignments Information Definitions

$\langle \text{MTV} \rangle ::= \{(\exists SE_{\Delta} \leftarrow O_1) \leftrightarrow (\exists TE_{\Delta} \leftarrow O_2) \cap (x \mid x \text{ is a threshold value})\}$
 $\langle \text{R} \rangle ::= \{(\exists SE_{\Delta} \leftarrow O_1) \leftrightarrow (\exists TE_{\Delta} \leftarrow O_2) \cap (x \mid x \text{ is relationship between SE and TE})\}$

Ontology Alignment Patterns

$\langle \text{PRM} \rangle ::=$ StringPRM | ChildPRM | LabelPRM | PropertyPRM
 | OverlapPRM | CustomizedPRM | SynonymPRM

BNF (Backus Normal Form)

Solution 3: Mediation Bridge Ontology (MBO) - Transformation Logic

$\langle \text{Logic} \rangle ::= \langle \text{LogicGM} \rangle \langle \text{LogicCM} \rangle$

$\langle \text{LogicGM} \rangle ::= \langle \text{Logic1} \rangle \langle \text{Logic2} \rangle \dots \langle \text{LogicN} \rangle \{ \text{where } N = 10 \}$

$\langle \text{Logic1} \rangle ::= \text{TE} \leftarrow \text{SE}$

$\langle \text{Logic2} \rangle ::= \{ \text{TE} \cap \{ \exists \text{TE.attribute} \wedge (\text{TE.attribute} \geq 1) \} \} \leftarrow \text{SE}$

$\langle \text{Logic3} \rangle ::= \text{TE} \leftarrow \{ \text{SE} \cap \{ \exists \text{SE.attribute} \wedge (\text{SE.attribute} \geq 1) \} \}$

$\langle \text{Logic4} \rangle ::= \{ \text{TE} \cap \{ \exists \text{TEChild} \subseteq \text{TE} \wedge (\text{TEChild} \geq 1) \} \} \leftarrow \text{SE}$

$\langle \text{Logic5} \rangle ::= \text{TE} \leftarrow \{ \text{SE} \cap \{ \exists \text{SEChild} \subseteq \text{SE} \wedge (\text{SEChild} \geq 1) \} \}$

$\langle \text{Logic6} \rangle ::= \text{TE} \leftarrow \{ \text{SE} \cap \{ (\exists \text{SEChild} \subseteq \text{SE}) \vee (\exists \text{SE.attribute}) \} \}$

$\langle \text{Logic7} \rangle ::= \{ \text{TE} \cap \{ (\exists \text{TEChild} \subseteq \text{SE}) \vee (\exists \text{TE.attribute}) \} \} \leftarrow \text{SE}$

$\langle \text{Logic8} \rangle ::= \{ \text{TE} \cap \{ (\exists \text{TEChild} \subseteq \text{SE}) \vee (\exists \text{TE.attribute}) \} \} \leftarrow \{ \text{SE} \cap \{ (\exists \text{SEChild} \subseteq \text{SE}) \vee (\exists \text{SE.attribute}) \} \}$

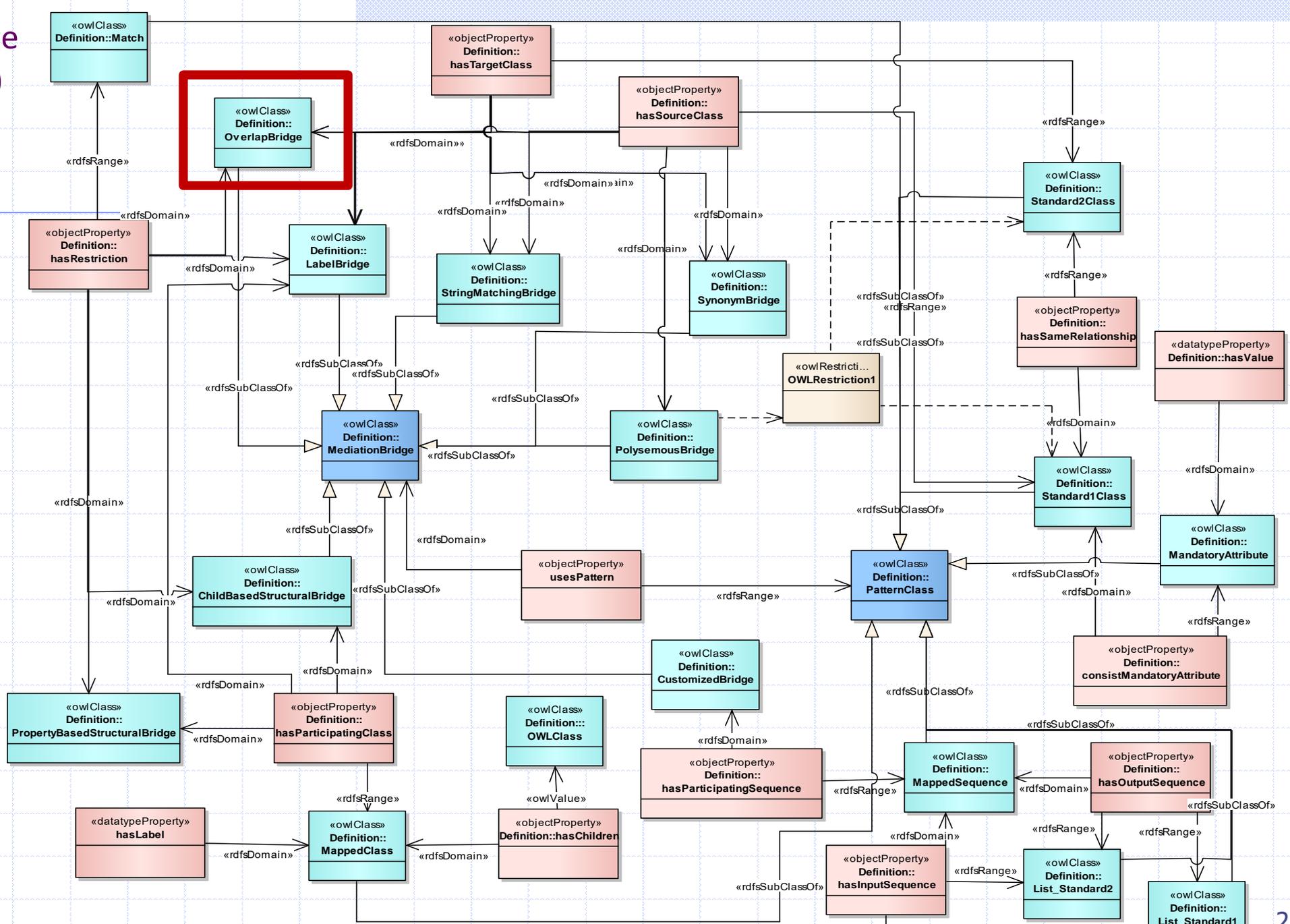
$\langle \text{Logic9} \rangle ::= \{ \text{TE} \cap \{ \exists \text{TEChild} \subseteq \text{TE} \wedge (\text{TEChild} \geq 1) \} \} \leftarrow \{ \text{SE} \cap \{ \exists \text{SE.attribute} \} \}$

$\langle \text{Logic10} \rangle ::= \{ \text{TE} \cap \{ \exists \text{TE.attribute} \wedge (\text{TE.attribute} \geq 1) \} \} \leftarrow \{ \text{SE} \cap \{ \exists \text{SEChild} \subseteq \text{SE} \} \}$

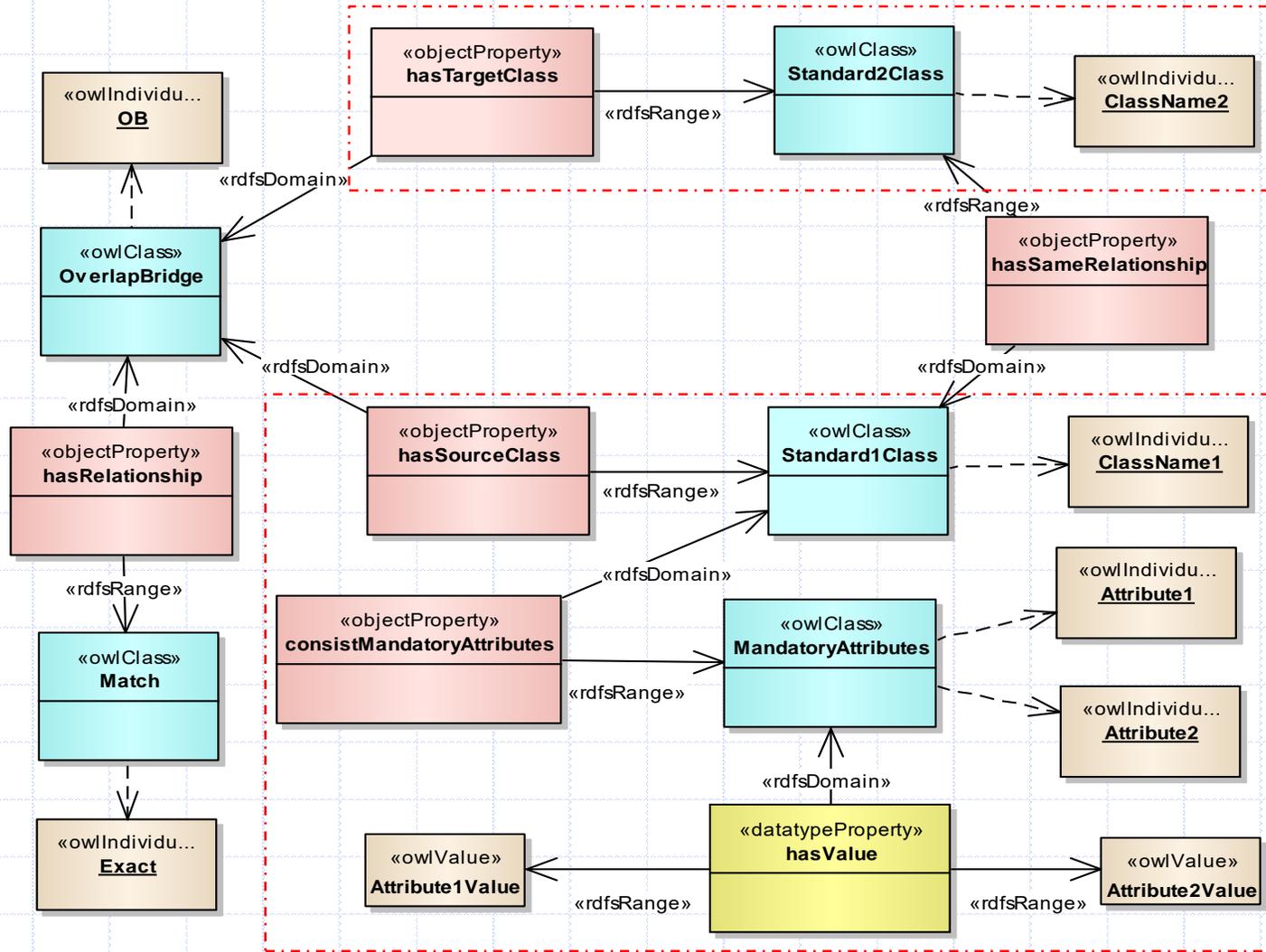
Existing Approaches Differences

- **Effective** mapping storage and representation
- **Structure** for Management of Ontology
- **Flexibility** for accommodating new matching dimensions
- **Understandability** for expert verifications
- **Mappings Personalization** for customized mapping

Mediation Bridge Ontology (MBO)



Overlap Pattern Relationship Model (PRM)



Overlap PRM – CDA and vMR Instance

```
<rdf:RDF
  xmlns:vmr="http://www.owl-ontologies.com/VMR.owl#"
  xmlns:cda="http://www.owl-ontologies.com/CDA.owl#">
  <owl:Ontology rdf:about="BridgeOntology"/>
```

<!-- Defining Classes for Overlap PRM-->

```
<owl:Class rdf:ID="OverlapBridge"/>
<owl:Class rdf:ID="MandatoryAttributes"/>
<owl:Class rdf:ID="Match"/>
<owl:Class rdf:ID="Standard1Class"/>
<owl:Class rdf:ID="Standard2Class"/>
```

<!-- Object Properties -->

```
<owl:ObjectProperty rdf:ID="consistMandatoryAttributes">
  <rdfs:domain rdf:resource="#Standard1Class"/>
  <rdfs:range rdf:resource="#MandatoryAttributes"/>
</owl:ObjectProperty>
```

MBO Alignment Information

- Validity of the information stored in MBO requires higher accuracy of transformation

<!-- CDA Class with its mandatory attributes and values -->

```
<Standard1Class rdf:ID="CDA_EntryRelationship">
  <hasSameRelationship rdf:resource="#RelatedClinicalStatement"/>
  <consistMandatoryAttributes rdf:resource="#TypeCode"/>
  <consistMandatoryAttributes rdf:resource="#ContextConductionInd"/>
</Standard1Class>
<owl:DatatypeProperty rdf:ID="hasValue">
  <rdfs:domain rdf:resource="#MandatoryAttributes"/>
  <rdfs:range rdf:resource="&xsd:string"/>
</owl:DatatypeProperty>
```

.....

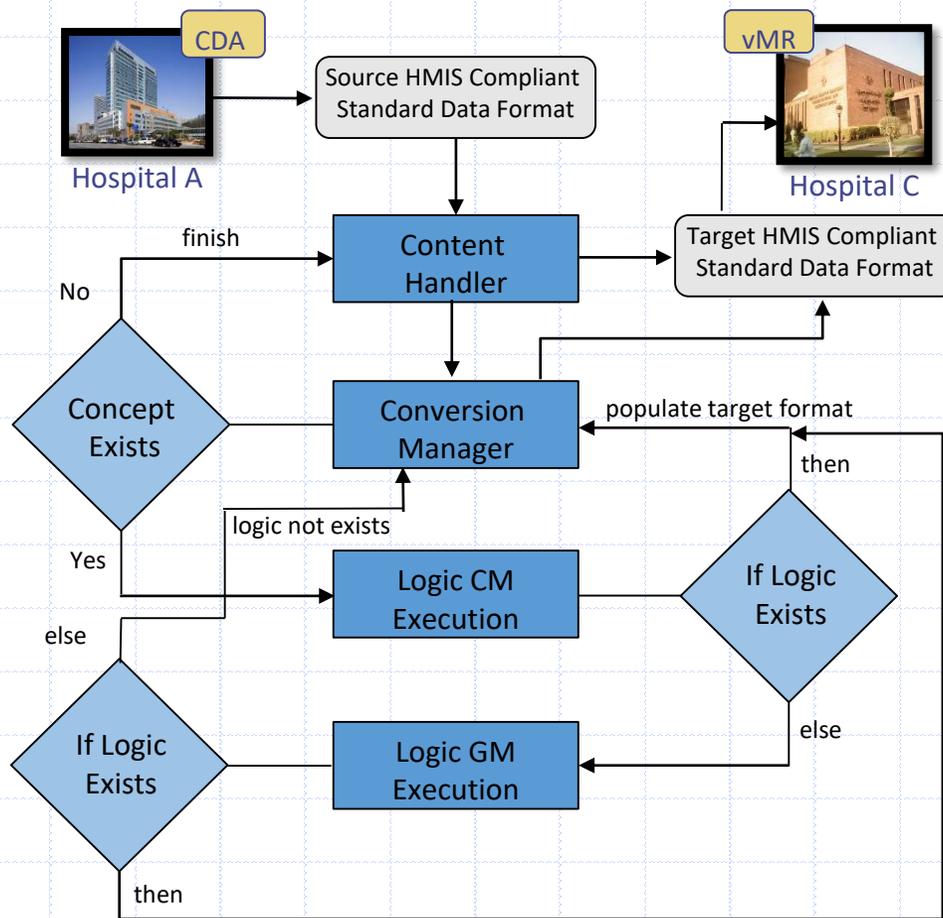
<!-- VMR Class -->

```
<Standard2Class rdf:ID="VMR_RelatedClinicalStatement"/>
```

<!-- Overlap Bridge Relationship -->

```
<OverlapBridge rdf:ID="OverlapBridgeInd">
  <hasSourceClass rdf:resource="#EntryRelationship"/>
  <hasRelationship rdf:resource="#Exact"/>
  <hasTargetClass rdf:resource="#RelatedClinicalStatement"/>
</OverlapBridge>
</rdf:RDF>
```

Solution 4: Transformation Process - Case Study



Blood Pressure: 127/ 79 mm[hg]
 Fasting blood glucose : 105 mg/dl
 Glucose measurement, 2 hour post prandial:
 114 mg/dl
 Hemoglobin A1C : 7%

Data

```

    <entry typeCode="COMP" contextConductionInd="true">
      <observation classCode="OBS" moodCode="EVN">
        <code code="271062006" displayName="Fasting blood glucose
          measurement (procedure)" codeSystem="2.16.840.1.113883.6.96"
          codeSystemName="SNOMED CT"/>
        <value xsi:type="PQ" value="105" unit="mg/dl"/>
      </observation>
    </entry>
  
```

CDA

CDA Concepts	vMR Concepts
Entry	RelatedClinicalStatement
Observation	ObservationResult
Code	ObservationFocus
Value	ObservationValue

Mappings

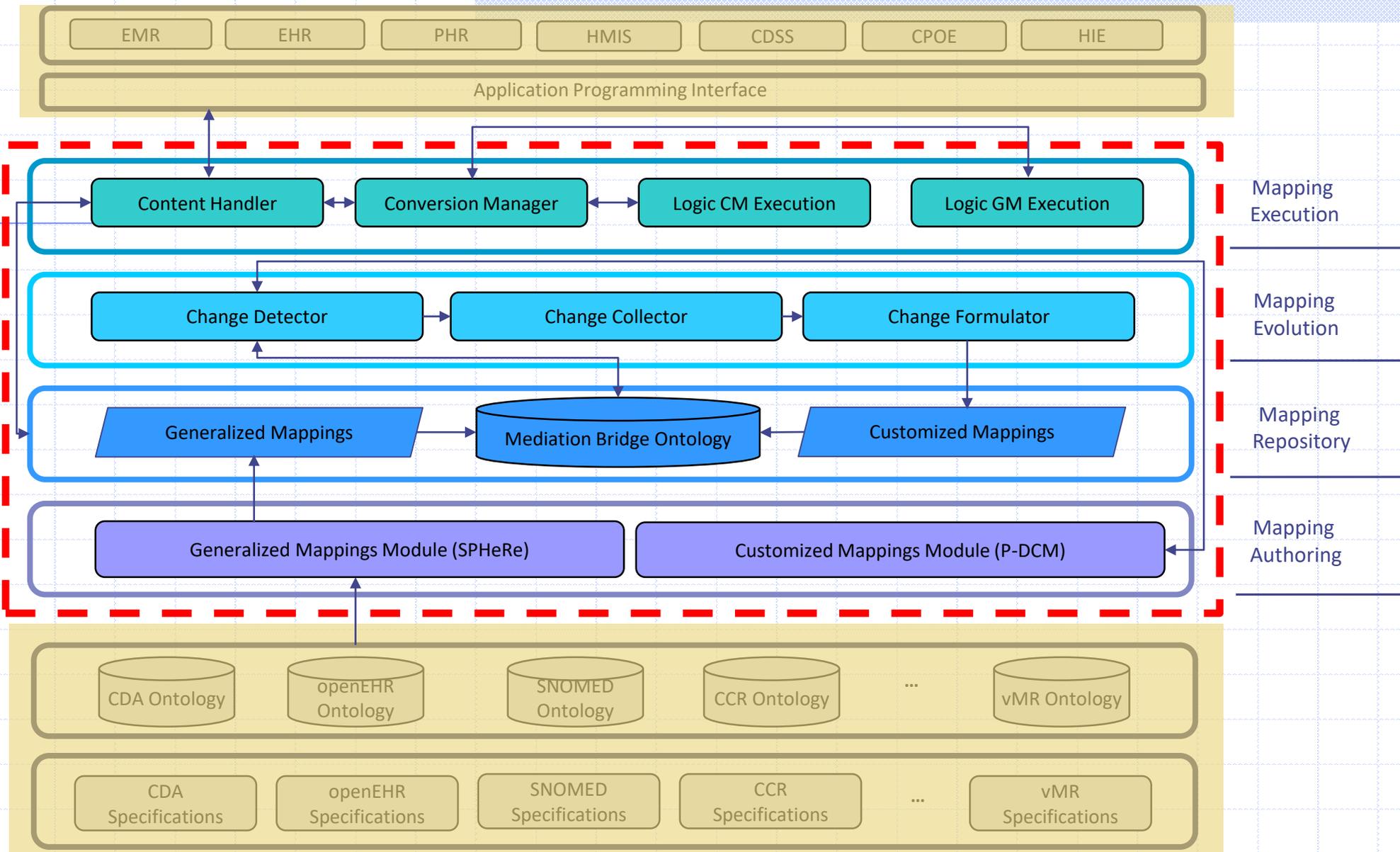
```

    <relatedClinicalStatement>
      <observationResult>
        <templateId root="2.16.840.1.113883.10.20.1.31"/>
        <id root="33d27880-eb74-11e0-9572-0800200c9a66"/>
        <observationFocus displayName="Fasting blood glucose
          measurement (procedure)" codeSystem="2.16.840.1.113883.6.96"
          code="271062006"/>
        <observationValue>
          <physicalQuantity value="105" unit="mg/dl"/>
        </observationValue>
      </observationResult>
    </relatedClinicalStatement>
  
```

vMR

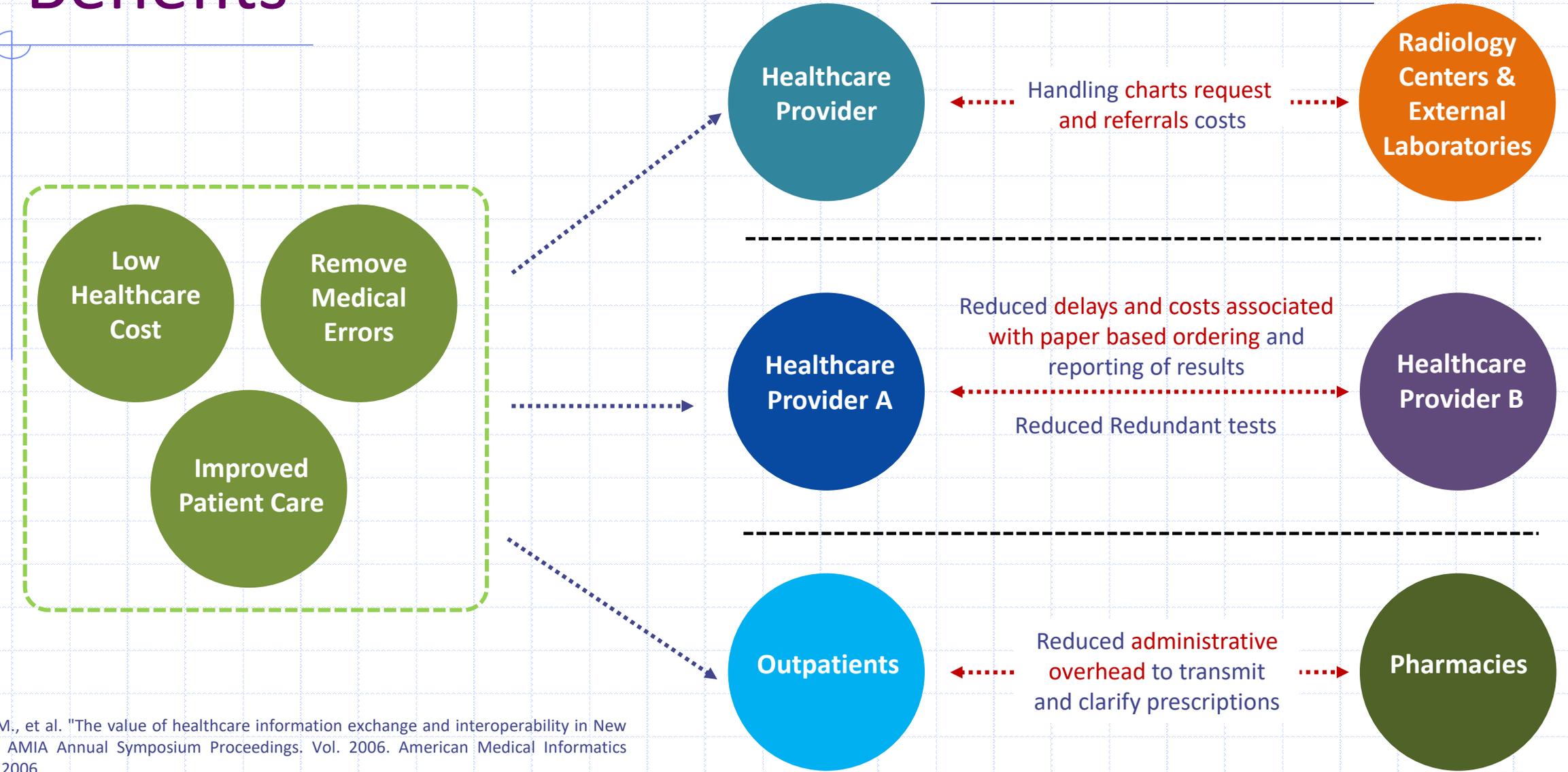
Proposed Architecture

Healthcare Semantic Reconciliation Framework



- **Wajahat Ali Khan**, Bilal Amin, AM Khattak, Maqbool Hussain, M Afzal, and Sungyoung Lee, "Object Oriented and Ontology Alignment Patterns based Expressive Mediation Bridge Ontology (MBO)", Journal of Information Science (SCIE, IF 1.2), 2014 [Accepted]
- **Wajahat Ali Khan**, AM Khattak, Maqbool Hussain, Bilal Amin, M Afzal, Christopher Nugent and Sungyoung Lee, "An Adaptive Semantic based Mediation System for Data Interoperability among Health Information Systems", Journal of Medical Systems (SCIE, IF 1.783), 2014
- **Wajahat Ali Khan**, Maqbool Hussain, Muhammad Afzal, Muhammad Bilal Amin, Muhammad Aamir Saleem and Sungyoung Lee, "Personalized-Detailed Clinical Model for Data Interoperability among Clinical Standards", Telemedicine and EHealth (SCI, IF:1.416), Vol. 19 Issue 8, pp.632-642, 2013
- **Wajahat Ali Khan**, Maqbool Hussain, Khalid Latif, Muhammad Afzal, Farooq Ahmad, Sungyoung Lee, "Process Interoperability in Healthcare Systems with Dynamic Semantic Web Services", Computing Journal (SCI, IF:0.701), Vol. 95, Issue 9, pp.837-862, 2013

Benefits



Hook, Julie M., et al. "The value of healthcare information exchange and interoperability in New York state." AMIA Annual Symposium Proceedings. Vol. 2006. American Medical Informatics Association, 2006.

Uniqueness and Contributions

SPHeRe Ontology Matching System

- ❑ Precision of 86% achieved in large biomedical ontologies dataset of OAEI
- ❑ Ranked in OAEI competition among top 15 systems

Mediation Bridge Ontology

- ❑ Low coupling factor value of 0.068
- ❑ High polymorphism value of 7
- ❑ Less rate of change value of 0.064

CDA vs vMR Transformation

- ❑ SPHeRe-80% accuracy while transformations
- ❑ SPHeRe and P-DCM approach-93% accuracy while transformations

Experiments Environment

◆ Datasets (15 Ontologies)

- HL7 (1), openEHR (6), CDA (1), vMR (1), SNOMED CT (2), FMA (2), NCI (2)

◆ Systems Comparison (12 Systems)

- SPHeRe
 - ◆ OAEI Ontology Matching Systems 2013 Competition
- Mediation Bridge Ontology
 - ◆ FALCON, LogMap
- Mapping Execution
 - ◆ CDA and vMR instances

Solution 1 Experimental Results – SPHeRe (OAEI Competition)

Large Biomed Track – Small FMA & NCI

S.No	System	Precision	Recall	F-Measure
1	LogMap-BK	0.95	0.88	0.91
2	YAM++	0.98	0.85	0.91
3	GOMMA	0.96	0.86	0.91
4	AML-BK-R	0.96	0.86	0.90
5	AML-BK	0.94	0.87	0.90
6	LogMap	0.95	0.85	0.90
7	AML-R	0.96	0.82	0.89
8	ODGOMS-v1.2	0.95	0.83	0.89
9	AML	0.95	0.83	0.89
10	LogMapLt	0.96	0.81	0.88
11	ODGOMS-v1.1	0.96	0.81	0.88
12	ServOMap	0.95	0.81	0.88
13	SPHeRe	0.96	0.77	0.86
14	Hotmatch	0.96	0.75	0.84
15	IAMA	0.98	0.58	0.73

Large Biomed Track – Whole FMA & NCI

S.No	System	Precision	Recall	F-Measure
1	YAM++	0.90	0.85	0.87
2	GOMMA	0.86	0.83	0.85
3	LogMap	0.87	0.79	0.83
4	LogMap-BK	0.87	0.79	0.83
5	AML-BK	0.82	0.79	0.80
6	AML-BK-R	0.83	0.78	0.80
7	AML-R	0.89	0.72	0.80
8	AML	0.88	0.73	0.80
9	SPHeRe	0.85	0.75	0.80
10	ServOMap	0.73	0.80	0.76
11	LogMapLt	0.69	0.81	0.74
12	IAMA	0.90	0.58	0.71

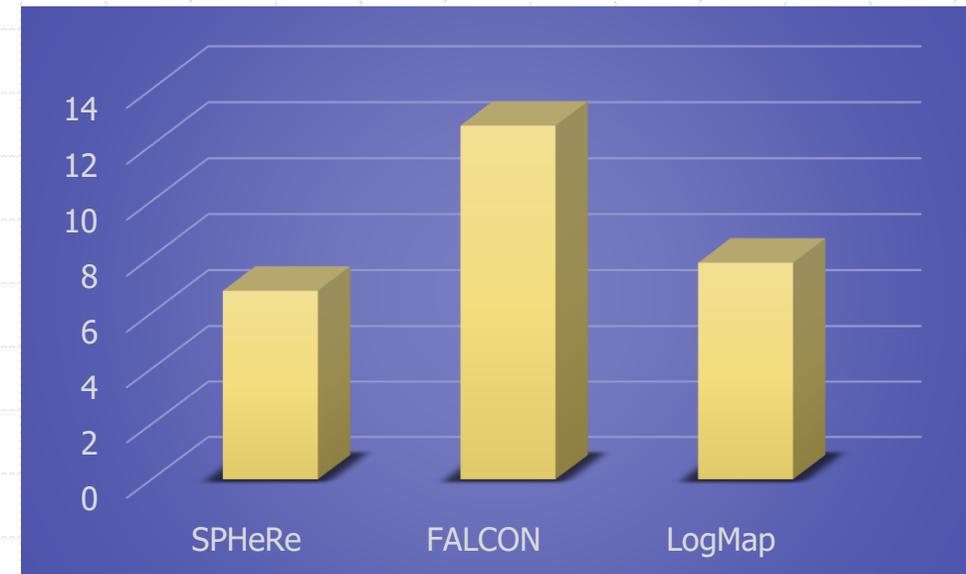
Solution 3 Experimental Results - MBO

LogMap and FALCON Systems Comparison

- ◆ Participation in OAEI
- ◆ Corresponding publications availability
- ◆ Its source code availability
- ◆ Complete system availability

◆ Coupling Factor (COF)

Systems	Actual Value	Scaling Factor	Scaled COF Value
MBO	0.068	100	6.8
LogMap	0.078	100	7.8
FALCON	0.127	100	12.7



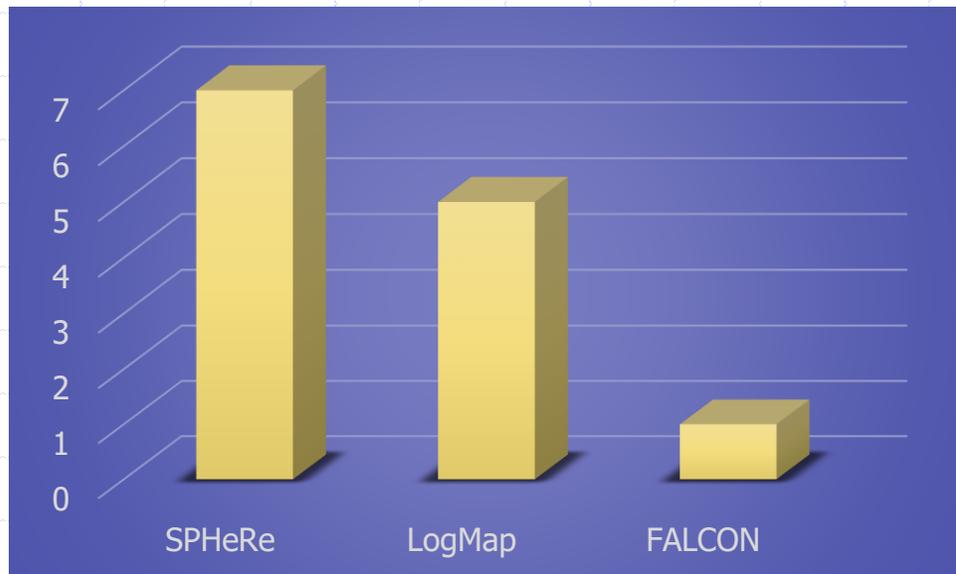
$$COF = \frac{df}{tc^2 - tc}$$

df: Total dependency factor
tc: Total no. of classes

Solution 3 Experimental Results - MBO

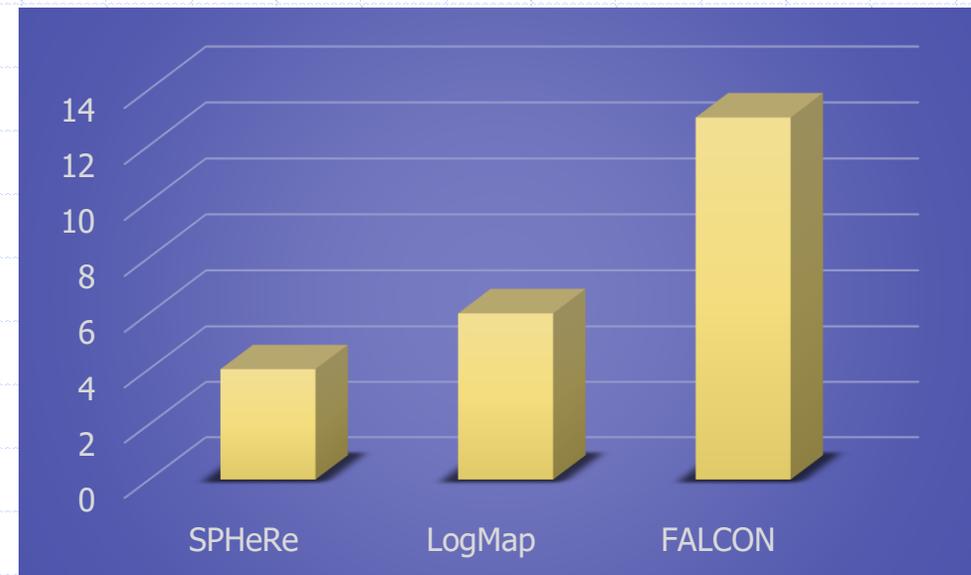
◆ Number of Polymorphic Methods (NOP)

Systems	NOP Value
MBO	7
LogMap	5
FALCON	1



◆ Rate of Change (RoC)

Systems	Actual Value	Scaling Factor	Scaled COF Value
MBO	0.004	1000	4
LogMap	0.006	1000	6
FALCON	0.013	1000	13



$$RoC = \frac{\Delta CoF}{CoF}$$

$$\Delta CoF = CoF - CoF'$$

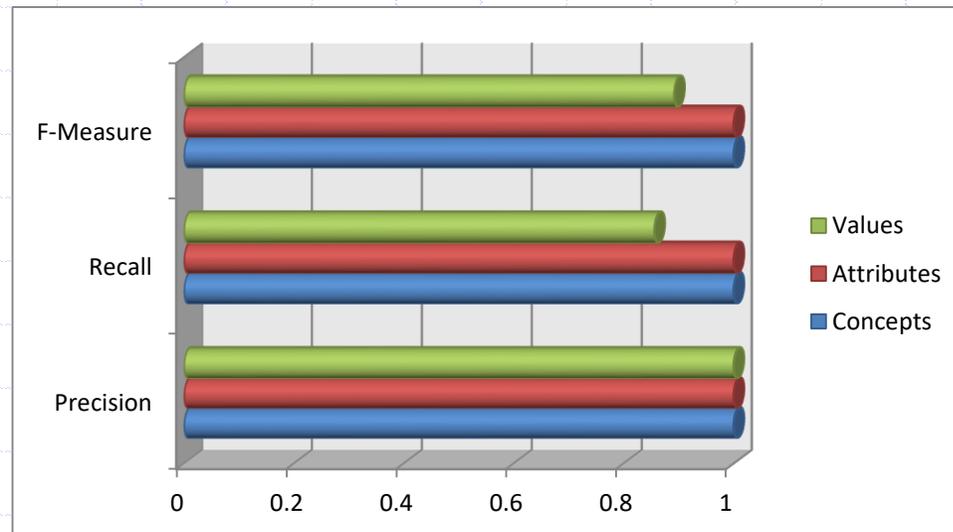
Solution 4 Experimental Results – SPHeRe, P-DCM, and MBO

Accuracy of System

CDA to vMR Transformations
(SPHeRe mappings in MBO)

Accuracy = 79%

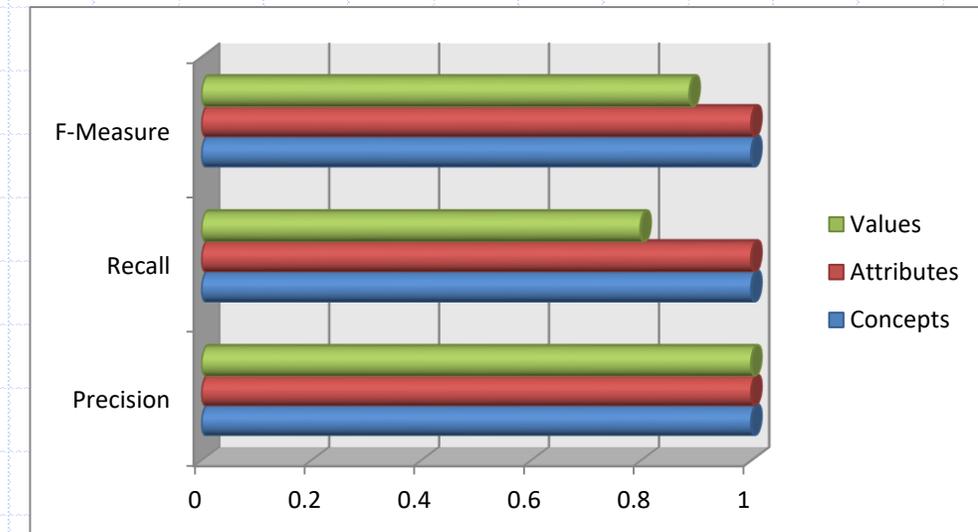
	Precision	Recall	F-Measure
Concepts	1	0.767	0.867
Attributes	1	0.799	0.888
Values	1	0.799	0.888



CDA to vMR Transformations
(SPHeRe and P-DCM mappings in MBO)

Accuracy = 93%

	Precision	Recall	F-Measure
Concepts	1	1	1
Attributes	1	1	1
Values	1	0.799	0.888

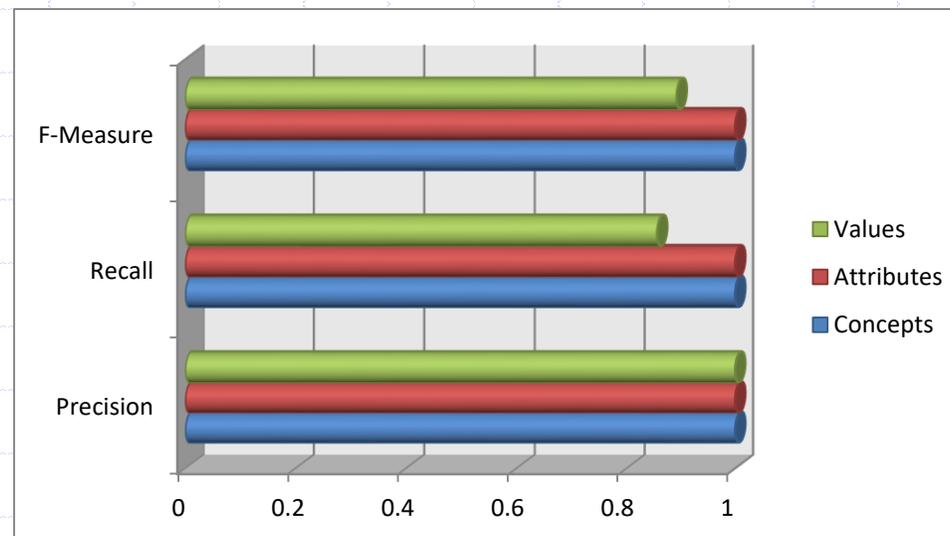


Solution 4 Experimental Results – SPHeRe, P-DCM, and MBO

Accuracy of System

vMR to CDA Transformations
(SPHeRe and P-DCM mappings in MBO)

	Precision	Recall	F-Measure
Concepts	1	1	1
Attributes	1	1	1
Values	1	0.856	0.922



Accuracy = 95%

Conclusion and Future Work

◆ This thesis contributes to:

Providing Interoperable Solutions

- Design and development of **Healthcare Semantic Reconciliation Framework** for mediation between medical systems compliant to different standards
- A high **degree of accuracy** in standard transformation process

Applying Semantic Reconciliations

- Effective mappings storage and representation in flexible and extendible **design patterns oriented MBO**
- Low **coupling factor, rate of change** and high **polymorphism** values in system design compared to existing systems

Resolving Semantic Heterogeneity

- Generalized mappings using **SPHeRe** ontology matching system
- Customized mappings handling using **P-DCM approach** for conformance issues handling

◆ Future Research

- **Mapping reconciliations in process interoperability**

Publications

◆ Patents (3)

- Three Korean

◆ SCI/ SCIE Journals (7)

- First Author- Three Published, 1 Accepted
- Co-Author- Two Published, 1 Accepted

◆ Non SCI Journals (1)

- Co-Author- One Published

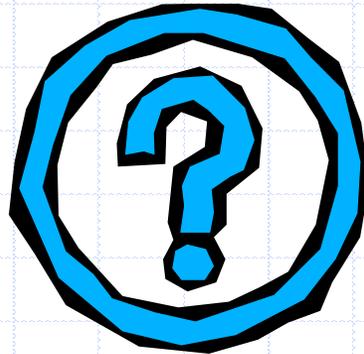
◆ Conferences (23)

- First Author- Seven Publications
- Co-Author- Fourteen Publications

Total Publications = 34

THANK YOU!

Any questions or comments?



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