An Ontology for Unmanned and Autonomous Systems of Systems Test and Evaluation

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Agenda

- Motivation for research
- What is an ontology?
- UASoS T&E ontology
  - Development method
  - Ontology overview
  - Ontology views
- Summary

Motivation for Research

- Significant growth in UAS demand and use
  - Driven by UAS benefits
    - New capabilities (e.g. persistent surveillance)
    - Remove personnel from undesirable activities ("dull, dangerous, dirty")
      - » Perform repetitive/boring and dirty missions
      - » Perform dangerous jobs (e.g. defusing IEDs, clearing minefields)

Motivation for Research

- New challenges for T&E community
  - Continuously increasing capability and complexity
  - Trend for rapid acquisition
  - Increased autonomy
  - Integration required with other systems as a component of a System of Systems (SoS) compounds complexity
  - Systems with capabilities at multiple maturity levels
  - Unplanned and undesirable emergent properties

Motivation for Research

- T&E planning activities for SoS
  - Time and resource constrained
    - Need to rapidly field systems
    - Inability to exhaustively test systems in SoS environment
  - Human intensive
    - Need to dynamically balance multiple criteria and resource constraints
    - However, multiple variables don't allow "eyeballing" solutions to test planning

Motivation for Research

- Prescriptive and Adaptive Test Framework (PATFrame) Project
  - Decision support system (DSS) targeted at early planning of T&E efforts for netcentric SoSs
  - Objective: accelerate and optimize test planning processes
    - Automated support of test planning tasks
    - Trade off multiple criteria using several methods
  - Project website: web.mit.edu/patframe [1]

Motivation for Research

- Prescriptive and Adaptive Test Framework (PATFrame) Project
  - Three university collaboration: Massachusetts Institute of Technology, University of Southern California, and The University of Texas at Arlington
    - Expertise in test & evaluation, decision theory, systems engineering, architecture, robotics, simulation and modeling
  - PATFrame project included multiple components
  - Preliminary knowledge model (ontology) developed in support of DSS

What is an Ontology?

- An ontology model describes a domain and represents important concepts
  - Ontologies can provide common views of important information to multidisciplinary users [2-4]
  - Provides "an explicit specification of a conceptualization" [5]
- An ontology can facilitate
  - Communication
    - between systems, between humans, and between humans and systems
  - Organization and reuse of knowledge
  - Computational inference [6]

UASoS T&E Ontology Purpose

- Provide a means to understand the entities, relationships, and terminology within the UASoS T&E domain
- Provide a common language and basis of understanding for UASoS T&E that can be leveraged as a foundation for other efforts
- Provide a common base of knowledge for multiple stakeholders and applications
- Facilitate knowledge agreement and reuse among stakeholders

Ontology Development Method

- Domain Knowledge Acquisition Process (DKAP) [7] ontology modeling methodology used to develop the ontology
- Steps applied from the method
  - Determine the purpose, domain, & scope of the ontology
  - Check availability of existing ontologies
  - Organize the project
  - Collect and analyze data
  - Develop initial ontology
  - Refine and validate ontology

Ontology Development Method

- Ontology purpose, domain and scope
  - Purpose and domain
    - Provide a common basis of understanding for UASoS T&E internal and external stakeholders
    - Leverage as a foundation for other project efforts
  - Scope
    - Defined an initial set of system requirements [8] for PATFrame DSS within UASoS T&E
      - Bounded information categories and depth of coverage
- Project organization
  - Ontology project organization included identifying key project tasks, due dates, and responsible personnel

Ontology Development Method

- Availability of existing ontologies
  - Performed literature reviews to gather information related to UASoS and T&E and other related domains

Name	Keywords
Test and Evaluation	**KW1.** Test, Test and Evaluation, Evaluation **KW2.** Ontology, Data Model, Object Oriented Model, Physical Representation, Logical Representation
Test Resources/ Infrastructure	**KW1.** Test Resources, Test Infrastructure **KW2.** Ontology, Data Model, Object Oriented Model, Physical Representation, Logical Representation
Unmanned & Autonomous Systems	**KW1.**Unmanned Autonomous Systems , Autonomous Systems, Unmanned Systems **KW2.**Characterize, Organize, Categorize, Ontology, Data Model
Systems of Systems	**KW1.**Systems of Systems **KW2.** Characterize, Organize, Categorize, Types, Classification, Ontology, Data Model
Emergence	**KW1.**Emergence , Emergent behavior, Emergent Properties **KW2.** Characterize, Organize, Categorize, Types, Classification, Ontology, Data Model, Hierarchy, Hierarchy levels ,Components
Risk	**KW1.**Risk, Risk Management **KW2.** Process, Ontology, Class Diagram, Object Model, Object Oriented model, Data Model, UML Class Diagram, Test, Taxonomy
Best Practices/ Lessons Learned	**KW1.**Best Practices, Lessons Learned **KW2.** Ontology, Data Model, Object Oriented Model, Classify, Taxonomy
Architecture	**KW1.**Architecture, **KW2.**Test, Test and Evaluation, Verification
Framework	**KW1.**Framework **KW2.** Test, Test and Evaluation, Verification
Simulation	**KW1.**Simulation **KW2.** Test, Test and Evaluation, Verification
Ontology	**KW1.**Ontology **KW2.** Kinds, types, Development, Methodology, representation, UML/OWL, evaluation

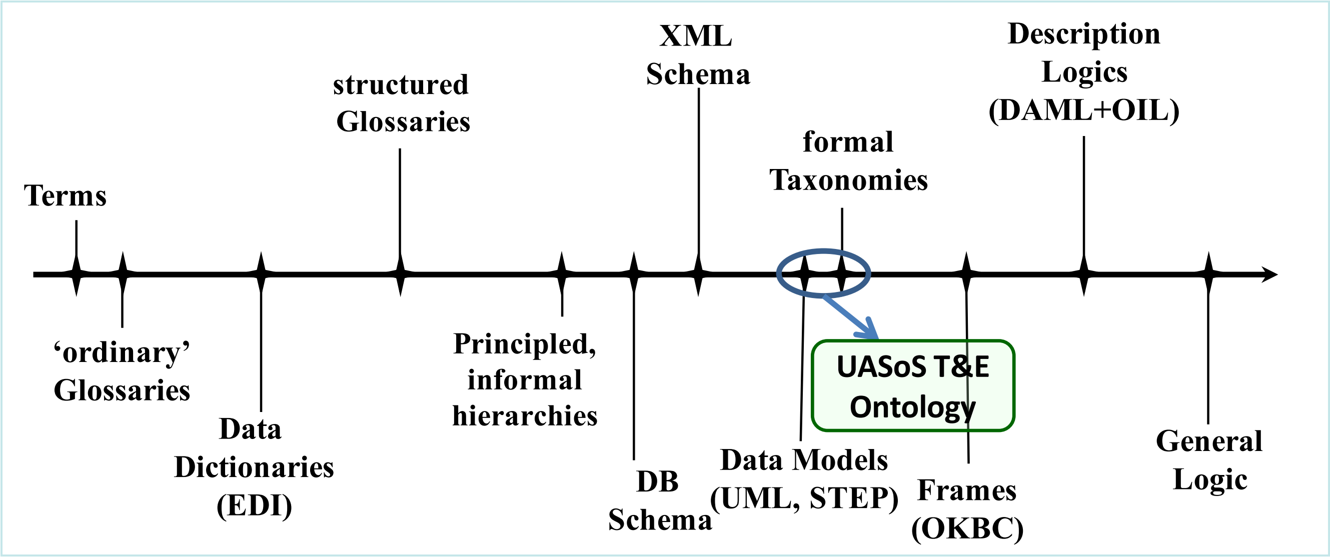
  - Existing T&E ontologies focused on specific sub-elements of the T&E process

Ontology Development Method

- Data collection and analysis
  - Performed literature reviews
  - Analyzed U.S. Army and Air Force T&E policies, standards, and training materials
  - Received information from
    - Joint Services and TRMC representatives attending PATFrame workshops
    - Subject matter experts from the Army and Air Force on the topic of T&E
    - NIST representatives to understand work related to UAS ontologies
    - Other ontology developers and subject matter experts & researchers for other ontology areas

Ontology Development Method

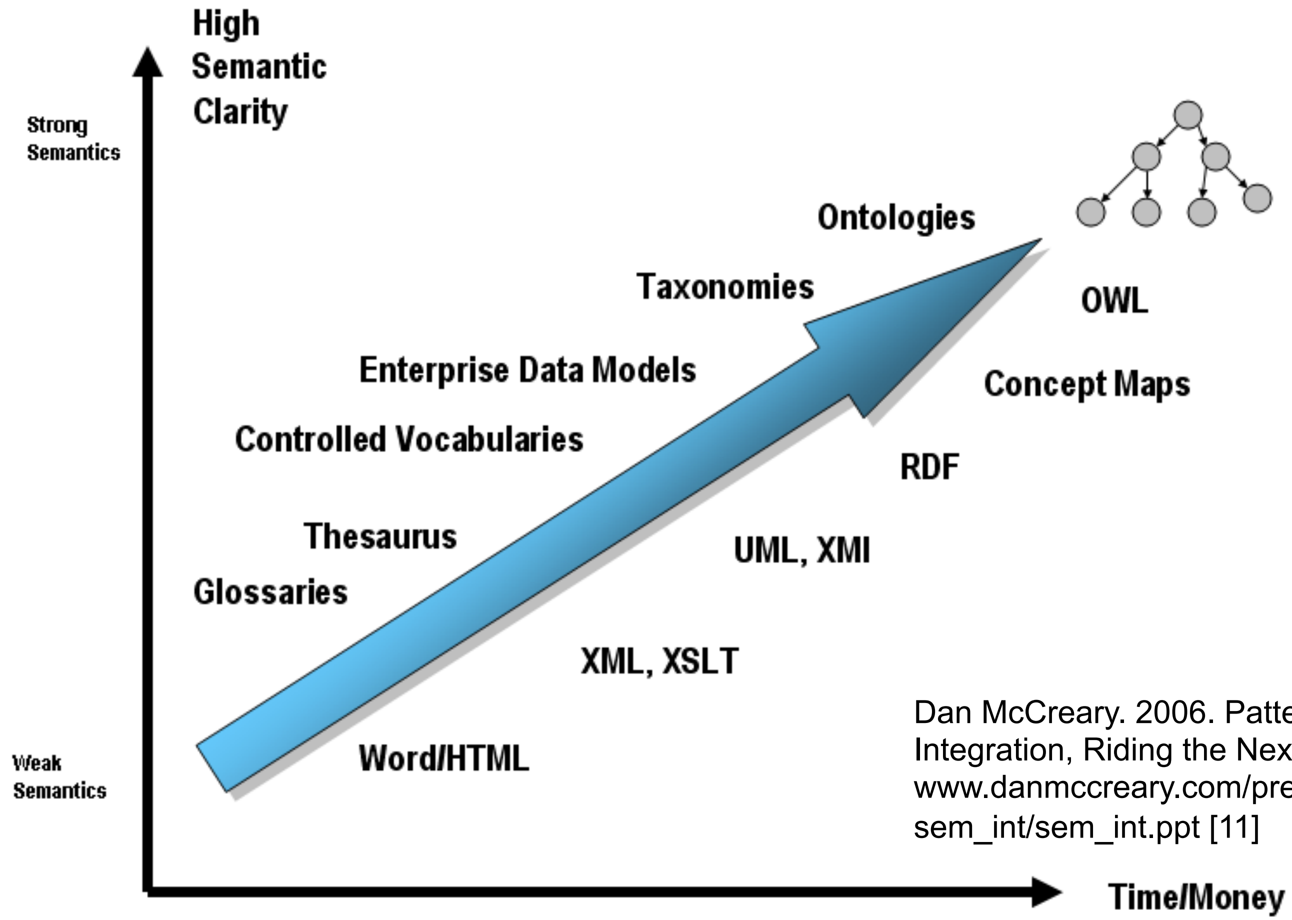
- Ontology representation
  - Ontologies can be represented on a continuum from highly informal to rigorously formal [9, 10]
- Ontology representation
  - Ontologies can be represented on a continuum from



Modified from Craig Schlenoff, Ontology Formalisms: What is Appropriate for Different Applications?, presentation, Modified from Craig Schlenoff, Ontology Formalisms: What is

Ontology Development Method

➢ Ontology representation



Dan McCreary. 2006. Patterns of Semantic Integration, Riding the Next Wave. http://www.danmccreary.com/presentations/sem_int/sem_int.ppt [11]

Ontology Development Method

- Ontology development, refinement and validation
  - UASoS T&E ontology represented using
    - Taxonomies
    - Class diagrams
    - Process flow
    - Data dictionary
  - Validation performed as products were available
  - Elements of the ontology presented at PATFrame workshops and discussed with subject matter experts
  - Work is expected to continue to refine and validate the model

Ontology Overview

- UASoS ontology categorized into views

View	
Organization	Shows the entities and relationships associated with the human resources, organization, and related information for T&E
Test and Evaluation Process and Artifacts	
Requirements and Capabilities	Shows the entities associated with requirements and capabilities and their relationships to resources and other key entities
Resource	Identifies the different types of resources involved as part of the T&E process
Emergence	Represents the emergent properties that are predicted and detected
Risk Management	Identifies the risk information associated to the T&E domain
Logical Architecture	Identifies the logical architecture entities and their relationship to resources
Physical Architecture	Identifies the physical architecture entities and their relationship to resources

Ontology Views

- Organization view
  –

Ontology Views

- Organization view

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Ontology Views

part of the T&E process

Ontology Views

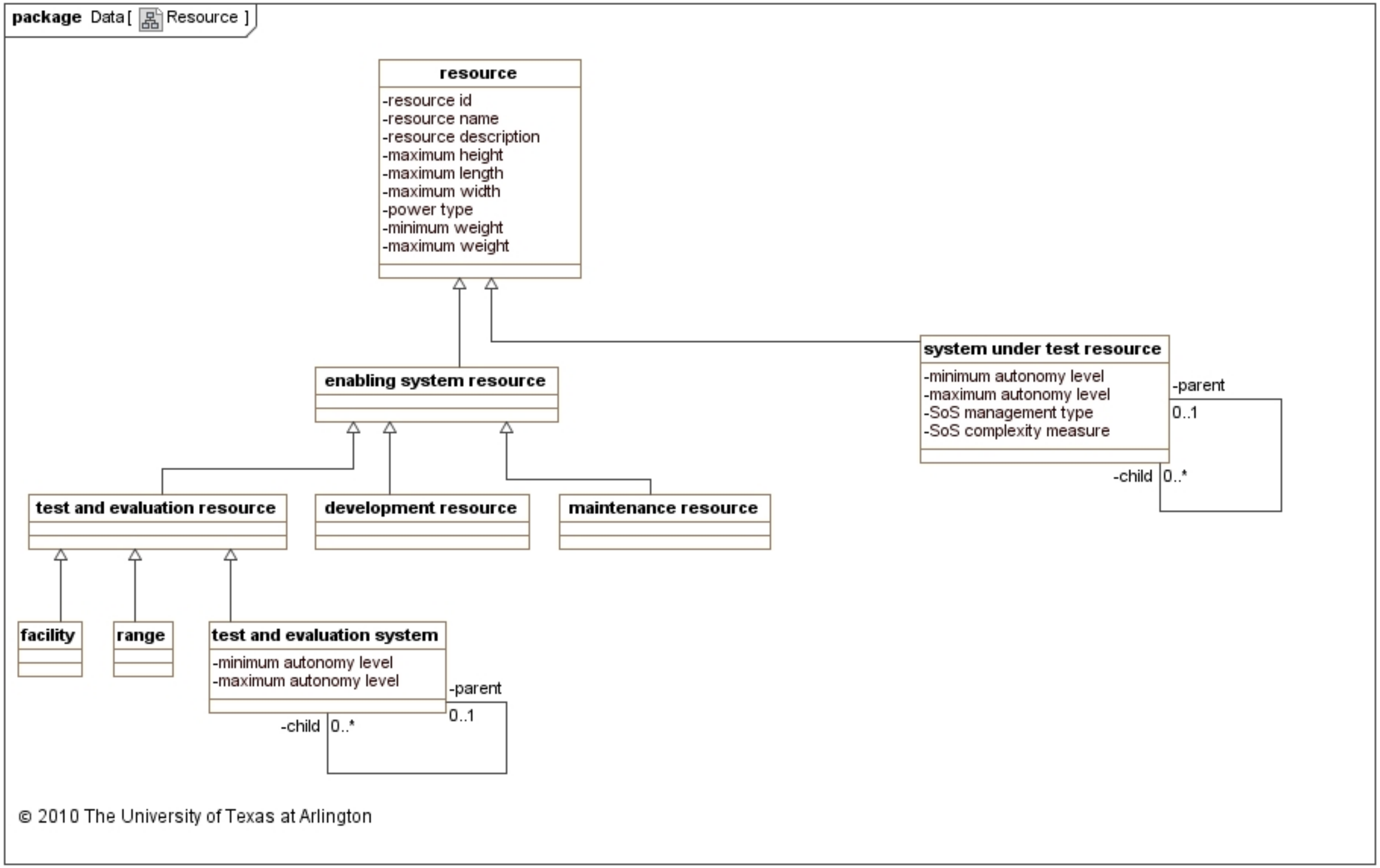
- How have we characterized Unmanned Autonomous Systems?
  - Autonomy levels based on ALFUS (Autonomy Levels for Unmanned Systems) framework [12]
    - Environmental complexity
    - Mission complexity
    - Human independence

Ontology Views

- How have we characterized Systems of Systems?
  - Limited characteristics found for Systems of Systems
  - Used SoS management type in Systems Engineering Guide for System of Systems [13]
    - SoS management type:
      - Virtual
      - Collaborative
      - Acknowledged
      - Directed
  - Extended with SoS complexity measure
    - Identified in brainstorming discussion with JoAnn Lane (SoS SME)

Ontology Views

- Resource view

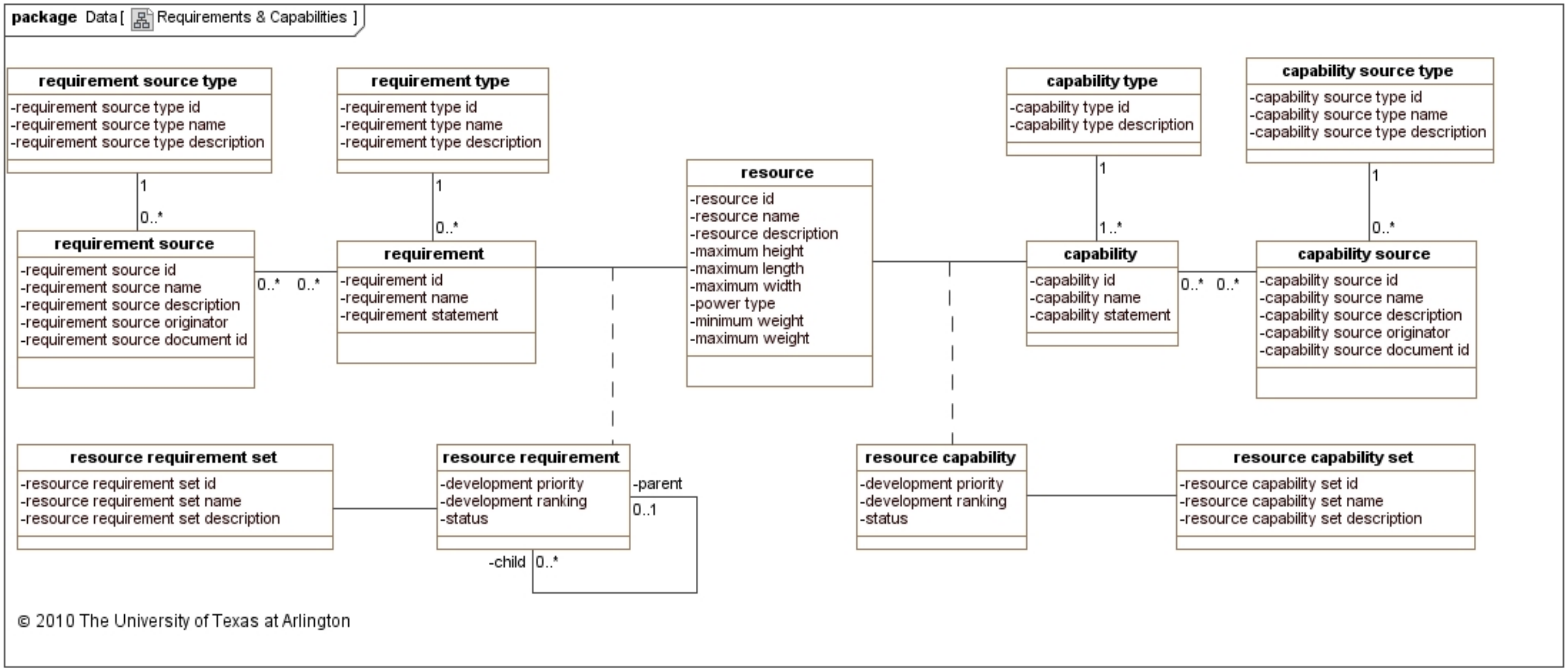


Ontology Views

- Requirements and capabilities view
  - Shows the entities associated with requirements and capabilities and their relationships to resources and other key entities

Ontology Views

- Requirements and capabilities view

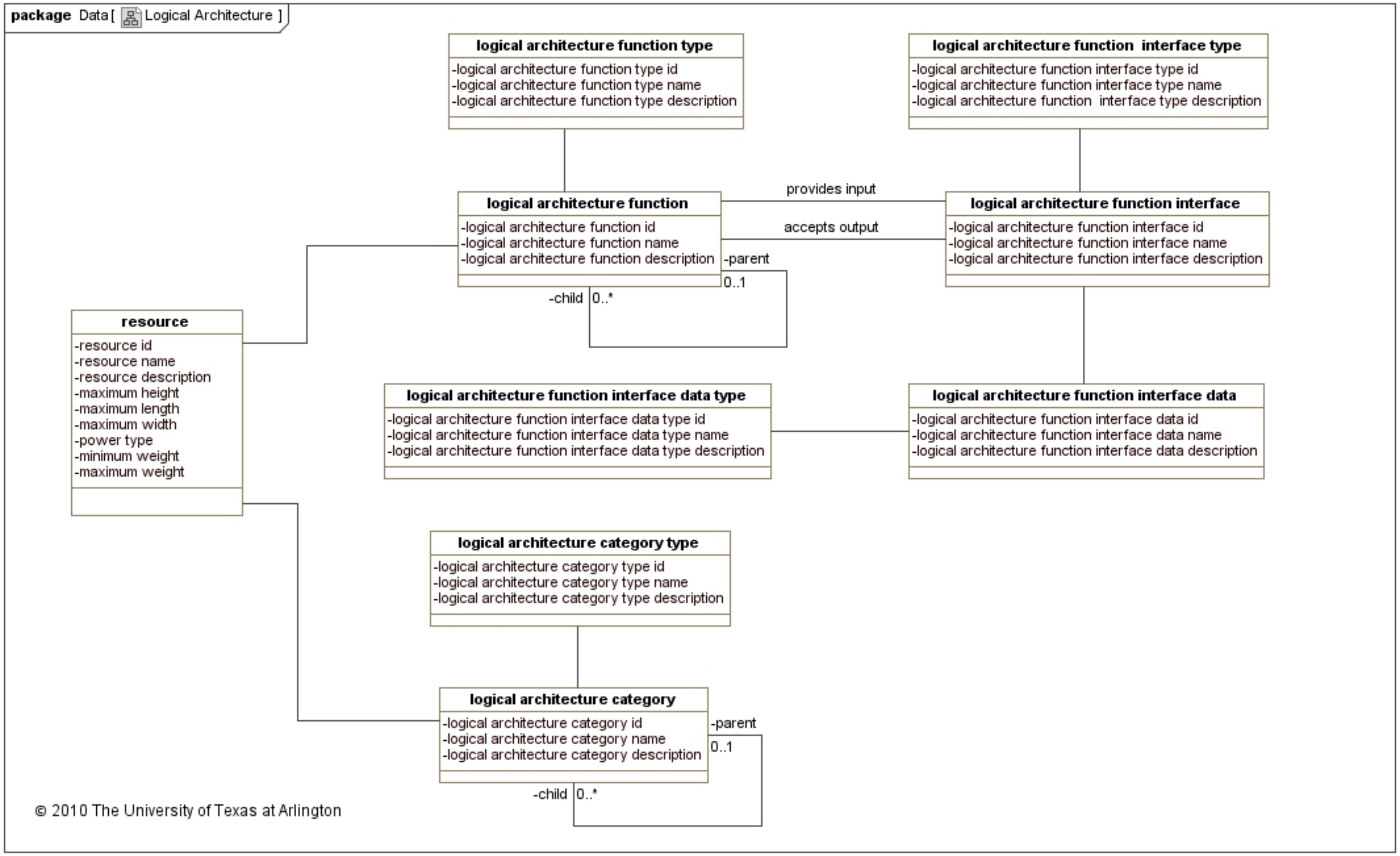


Ontology Views

- Logical architecture view
  - Identifies the logical architecture entities and their relationship to resources

Ontology Views

- Logical architecture view

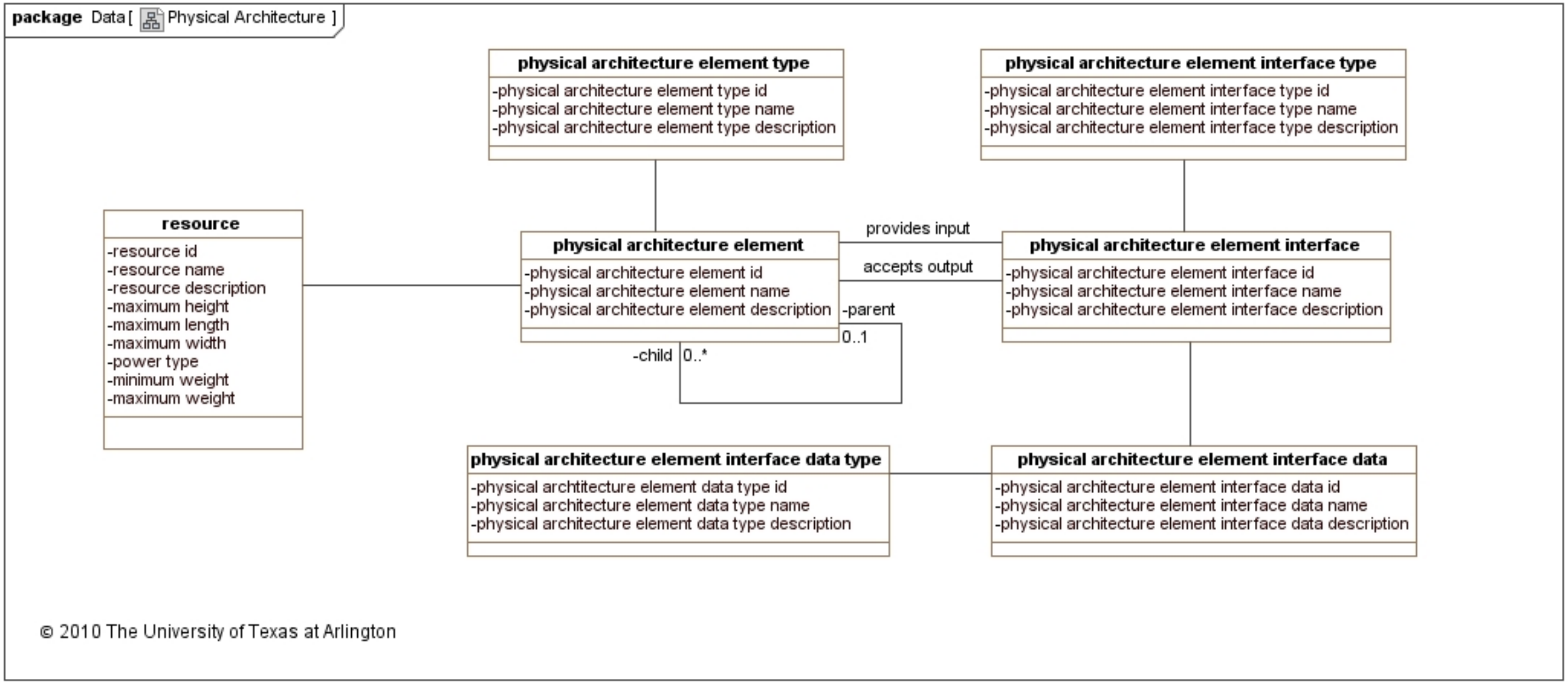


Ontology Views

- Physical architecture view
  - Identifies the physical architecture entities and their relationship to resources

Ontology Views

- Physical architecture view

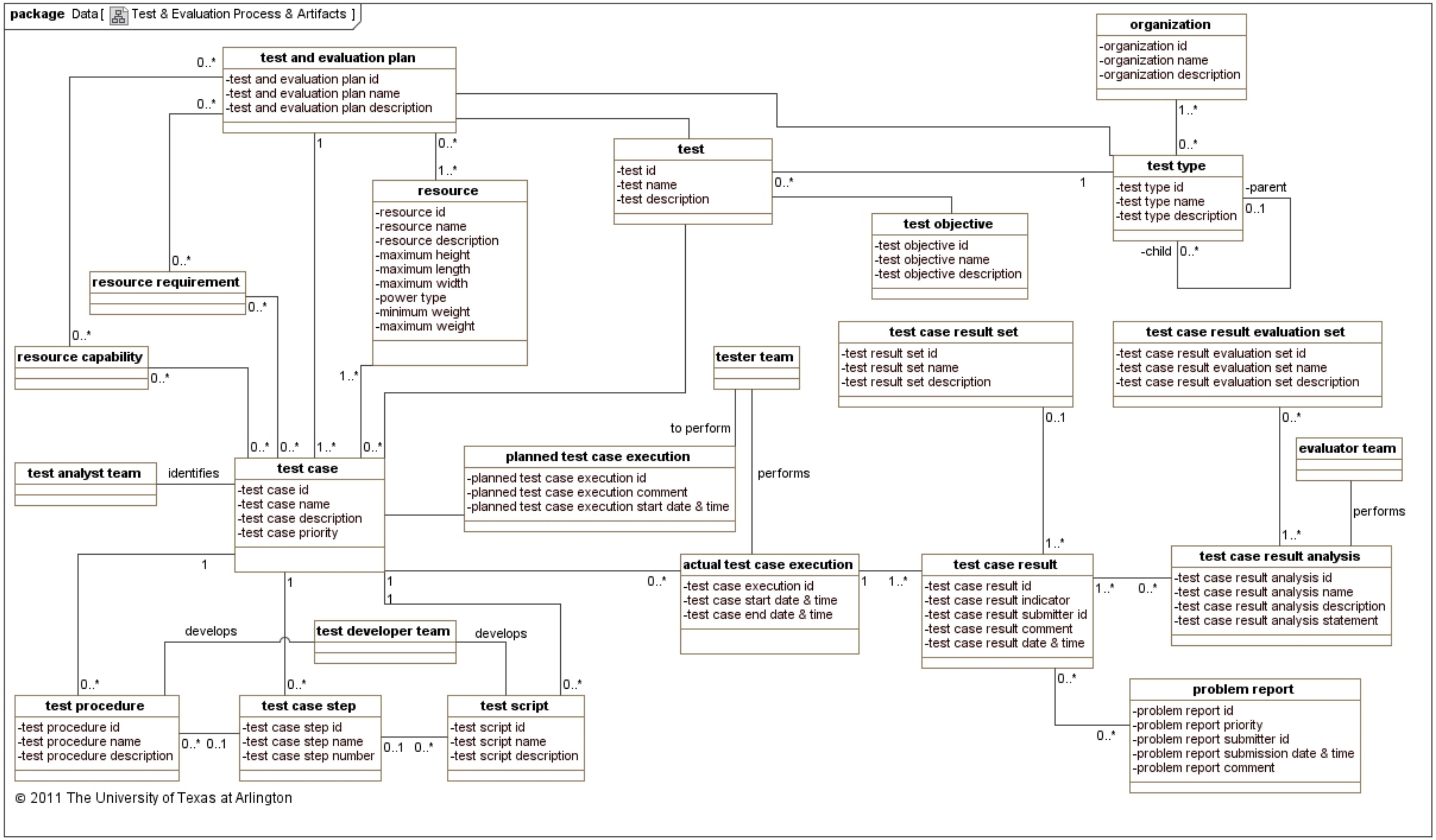


Ontology Views

- Test and evaluation process and artifacts view
  - Identifies the key artifacts produced throughout the T&E process, from test planning to the evaluation of test results

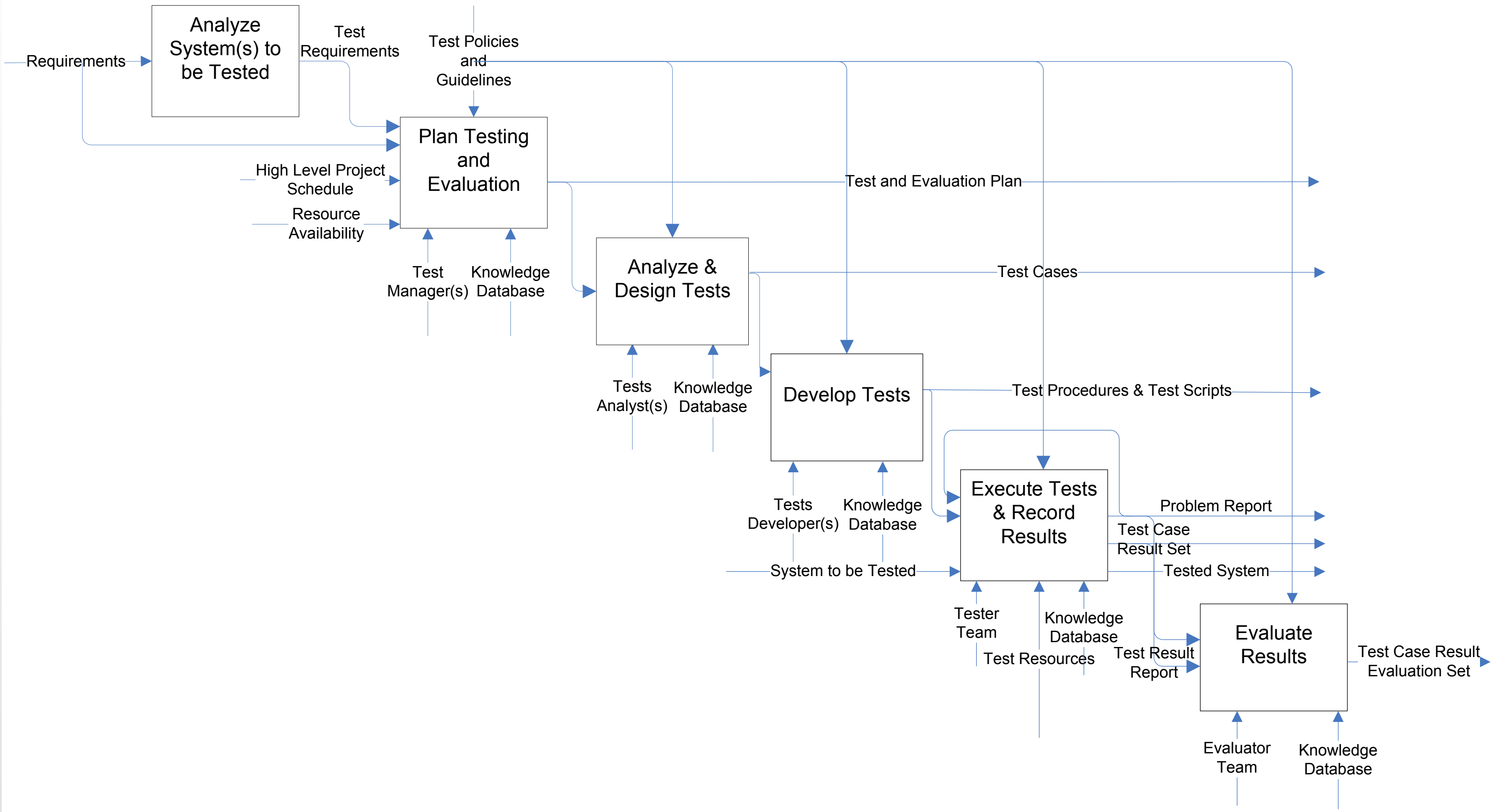
Ontology Views

- Test and evaluation process and artifacts view



Ontology Views

- Test and evaluation process

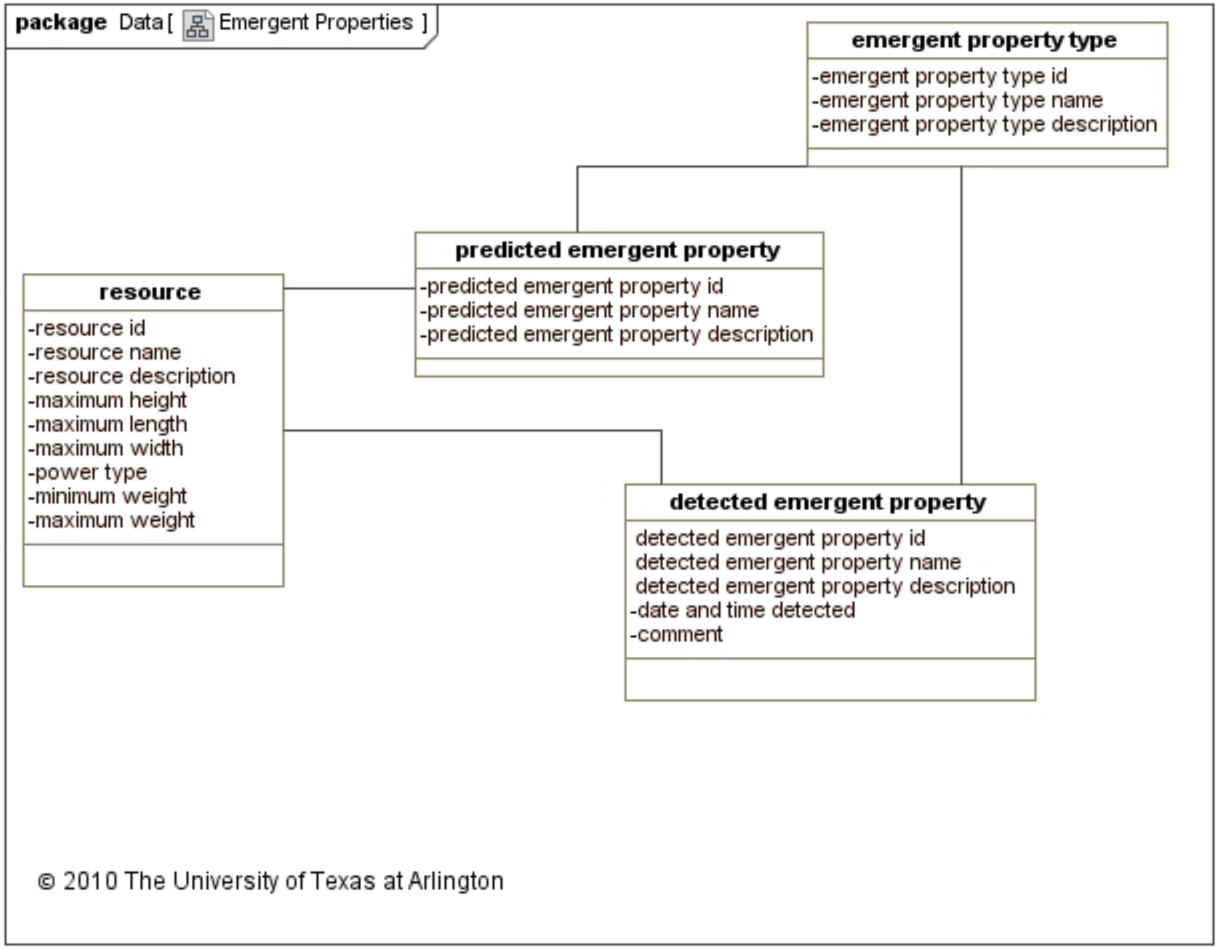


Ontology Views

- Emergence view
  - Represents the emergent properties that are predicted and detected
  - Properties emerge from a system as a result of interactions between components
  - Analogy of functional and nonfunctional requirements for taxonomy
    - Planned as well as unplanned emergence
    - Desirable as well as undesirable emergence

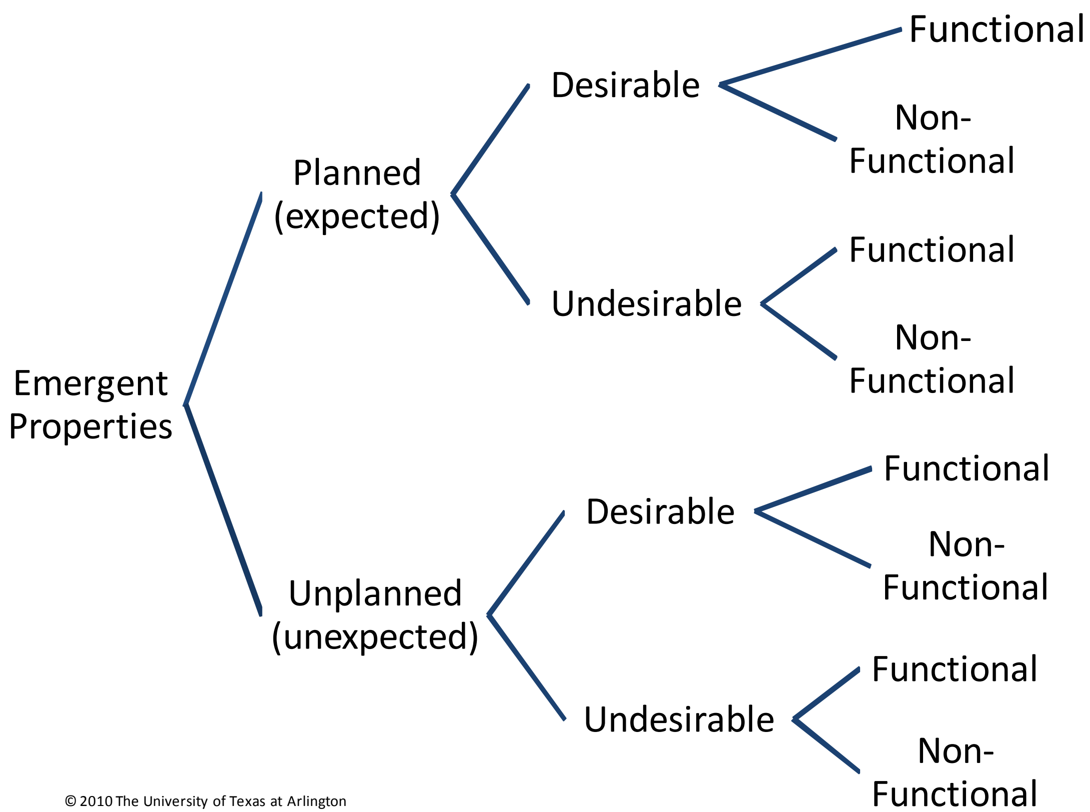
Ontology Views

- Emergence view



Ontology Views

➢ Emergent properties taxonomy

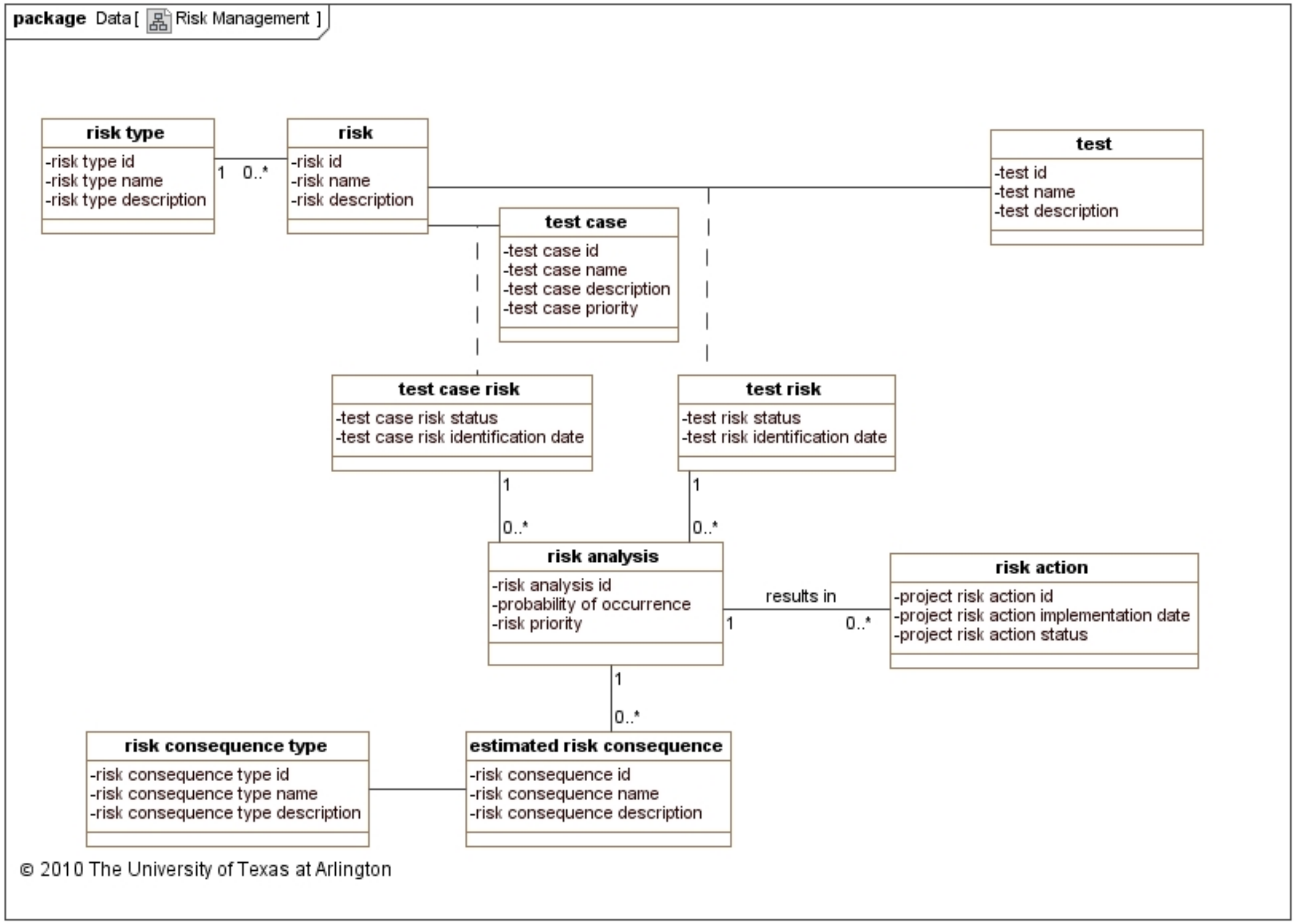


Ontology Views

- Risk management view
  - Identifies the risk information associated to the T&E domain
  - Assumed use of DoD risk management process [14]
  - Reviewed existing ontology and data models from Tah, Gusmao (OntoPrime, mPrime), Falbo
    - Used generic and basic concepts
  - Modified to simplify and extended to address test specific risks

Ontology Views

- Risk management view



Ontology Details

- Data dictionary example

Enabling system resource	A resource that complements a system-of-interest during its life cycle stages but does not necessarily contribute directly to its function during operation. [Source: modified from ISO/IEC 15288:2008, replaced "system" with "resource"]
Environmental complexity	One of the three-aspects associated with the Autonomy Levels for Unmanned Systems (ALFUS) metric model. Provides a means to characterize the complexity of the environment within which missions are performed. Environmental complexity considers factors such as: static environment, dynamic environment, electronic/electromagnetic environment, mobility, mapping and navigation, urban environment, rural environment, weather, operational environment. [Source: derived from Autonomy Levels for Unmanned Systems (ALFUS) Framework, Volume II: Framework Models Version 1.0, December, 2007. Source quote: "A UMS's CAC is characterized by the missions that the system is capable of performing, the environments within which the missions are performed, and human independence that can be allowed in the performance of the missions"]
Estimated risk consequence	Estimated consequence as a result of performing risk analysis. Predicted impact of an identified risk based on risk analysis.

Summary

- The UASoS T&E ontology provides a common foundation of understanding for the UASoS T&E domain
- Provides a common reference language for UASoS T&E that can be leveraged for other efforts
- The ontology draws on
  - Existing ontology efforts
  - Knowledge gathered from literature surveys and discussions with subject matter experts
- Additional work is expected to be performed to extend, refine, and validate the ontology

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