An Upper Ontology of Event Classifications and Relations

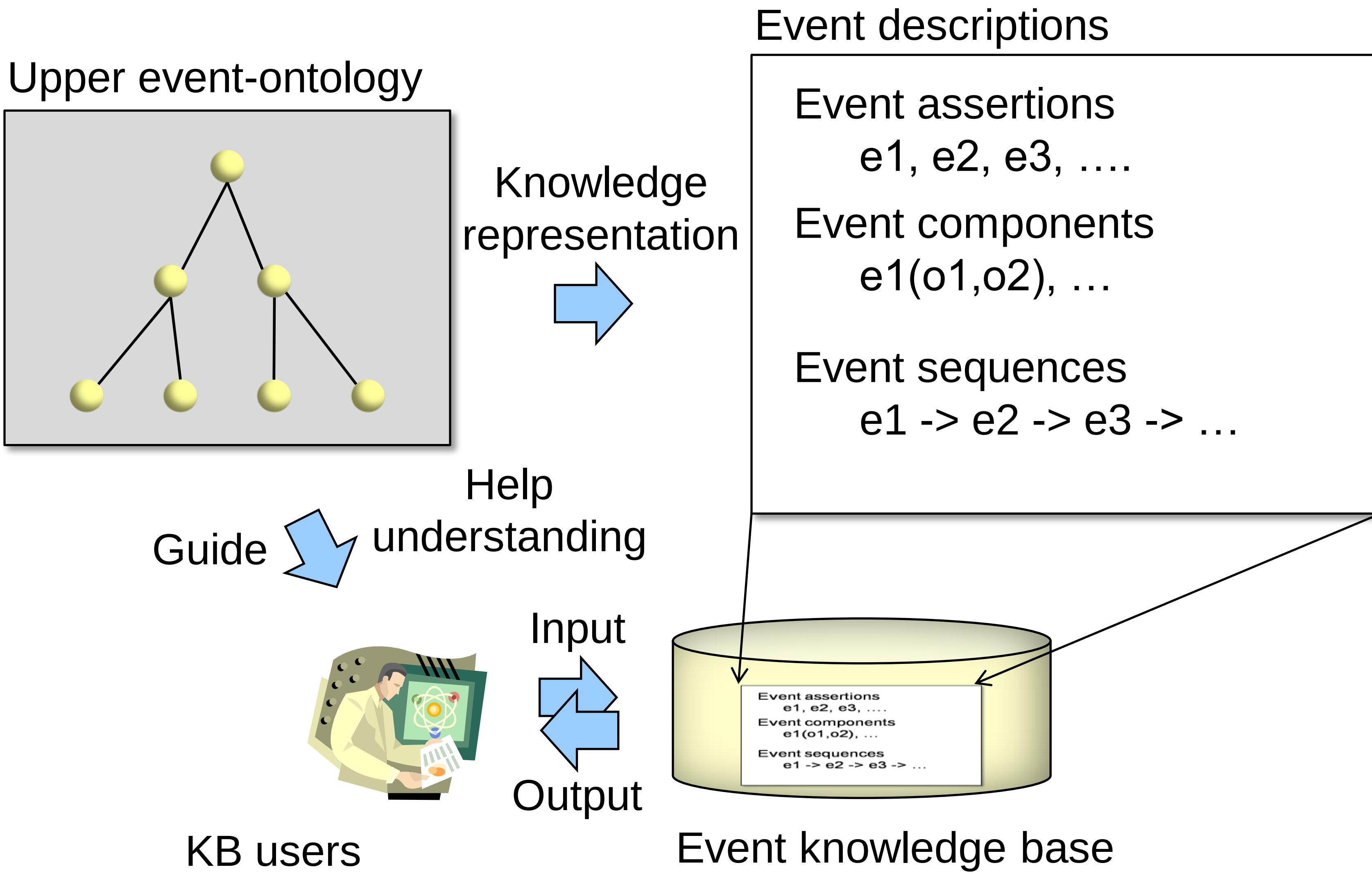
Ken Kaneiwa and Michiaki Iwazume
National Institute of Information and Communications Technology (NICT), Japan

Ken Fukuda
National Institute of Advanced Industrial Science and Technology (AIST), Japan

Objectives

- Providing an infrastructure for designing event knowledge bases.
- Understanding what events are and what the differences are between events and other entities in knowledge representation.
- Defining errors from event assertions and event sequences in the knowledge bases.

Event Knowledge Bases



Our Approach

- An upper-level event-ontology is constructed by a sort-hierarchy in order-sorted logic and by logical formulas in modal logic.
- The sort-hierarchy builds event classifications such a way that each event class is denoted by a sort.
- The modal logical formulas represent the semantic functions of events, i.e., each event functionally affects objects and the real world.
- Event relations (event class and instance relations) are variously defined in order to describe event sequences.

Related Work

SUMO [IEEE Standard Upper Ontology Working Group]

- Suggested Upper Merged Ontology(20,000 terms and 60,000 axioms)
- Process => Physical => Entity

WordNet 2.1 for Win [2005]

- A large lexical database of English
- Nouns, verbs, adjectives and adverbs as cognitive synonyms
- Conceptual-semantic and lexical relations: ISA and Part-Of relations
- Process => Activity => Event => Psychological feature => …. => Entity

OpenCyc 1.0 [2006]

- Terms and assertions relating the terms to each other (6,000 concepts and 60,000 facts)
- Event => Temporal Thing & Intangible => Individual

DOLCE 2.1 [Guarino's group]

- Description Ontology for Linguistic and Cognitive Engineering
- Described using first-order logic, and translated to OWL
- Process, Event, Phenomena, Activity and State => Perdurant (Occurrence) => Entity

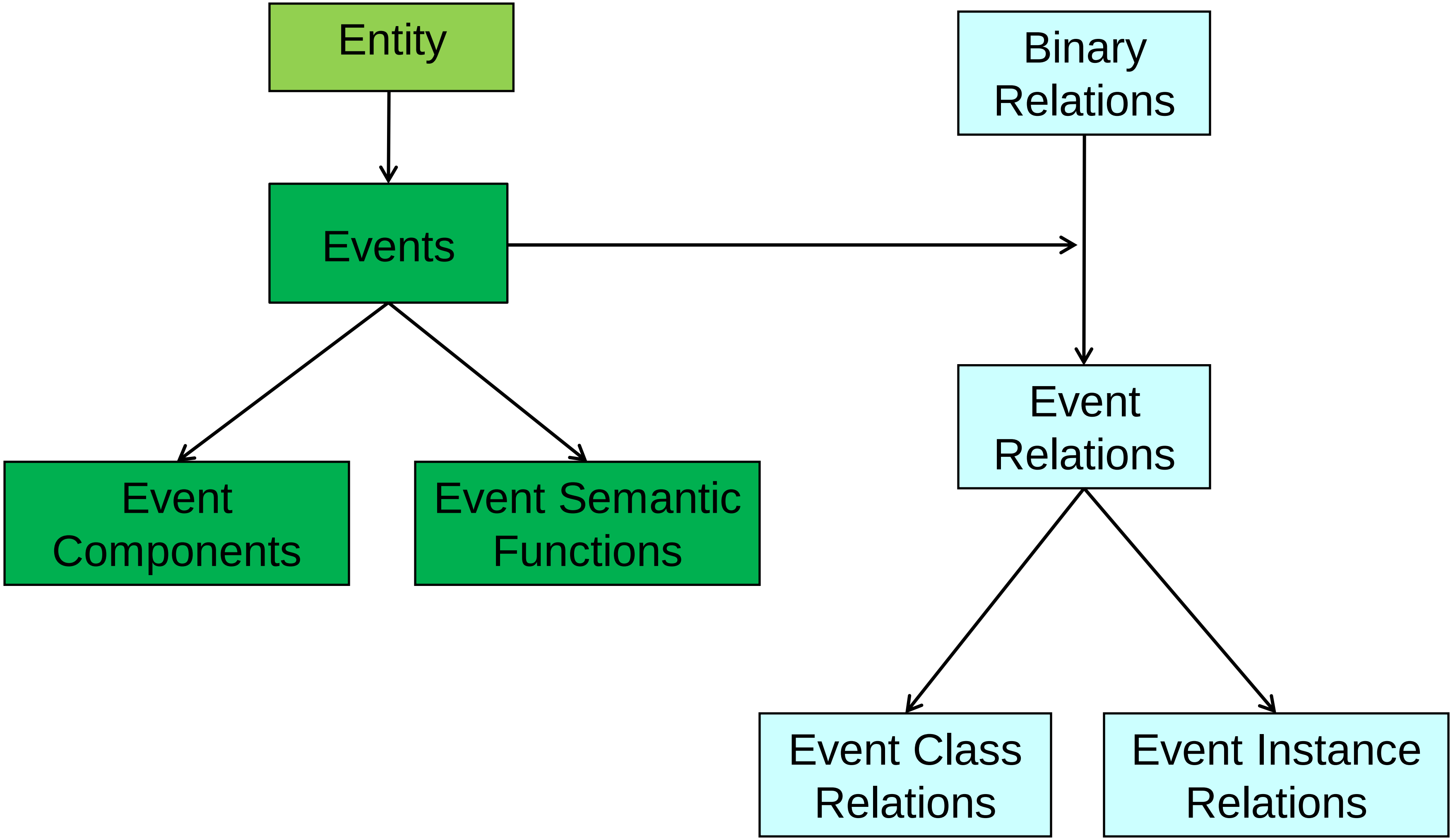
BFO [Smith & Grenon]

- Basic Formal Ontology
- SNAP (ontologies for substances like 3-D objects)
- SPAN (a single ontology for processes and space and time)
- In SPAN, Process => Processual Entity => Occurrent

GEM [Worboys 2004]

- Geospatial Event Model
- The introduction of events into object-based paradigm
- Object-object, object-event, event-object, and event-event relationships

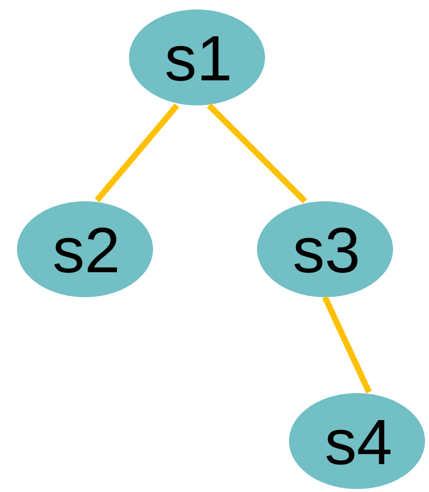
Overview: An Upper Event Ontology



Ontology Description

We describe an ontology by using the following sort-hierarchy:

Sort s1
- Subsort s2
- Subsort s3
  - Subsubsort s4



Subsort relation:

s4<s3, s3<s1, s2<s1

N-ary predicate declaration:

E:<s1,…,sn>

Argument structures

Help:<Person,Person>

Event Instance Tom helped John.

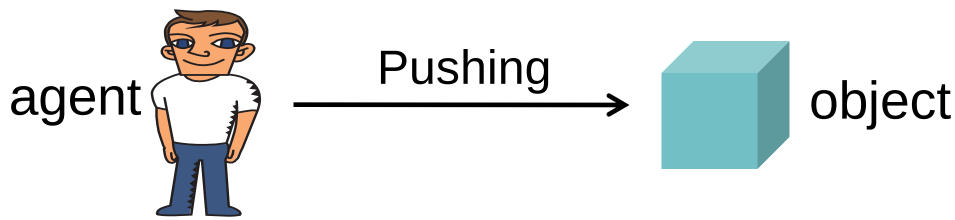
Tom instance-of Person
John instance-of Person

Event Classifications

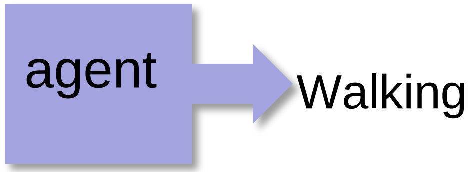
- Event
  - Natural Event
    - Occurrence1: <Time,Location>
    - Occurrence2: <Object,Time,Location>
  - Artificial Event
    - Action1: <Agent,Object,Time,Location>
    - Action2: <Agent,Time,Location>
    - Action3: <AgentGroup,Time,Location>
  - Dynamic State
    - Object State: <Object,Time,Location>
    - Environment State: <Time,Location>
  - Static State
    - Object State: <Object, Time,Location>
    - Environment State: <Time,Location>

Three Types of Artificial Events

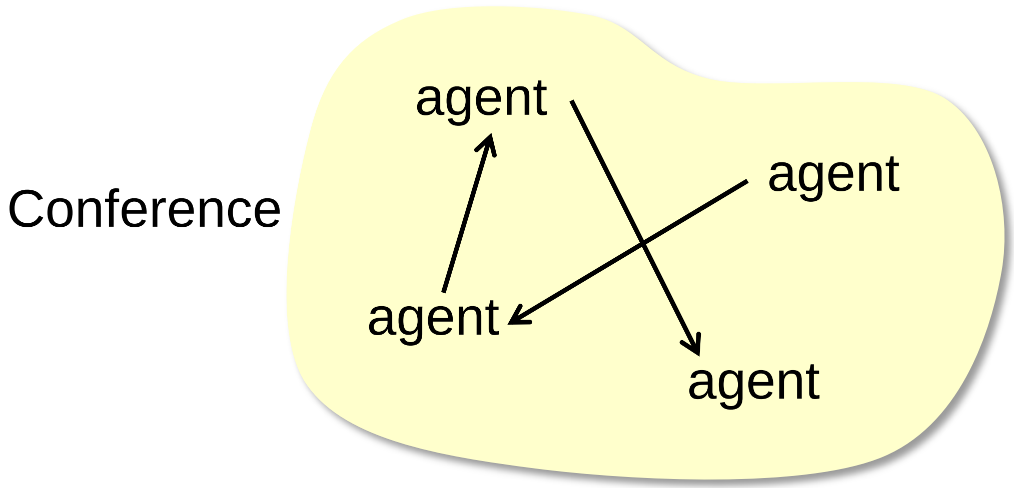
Action1: <Agent,Object,Time,Location>



Action2: <Agent,Time,Location>



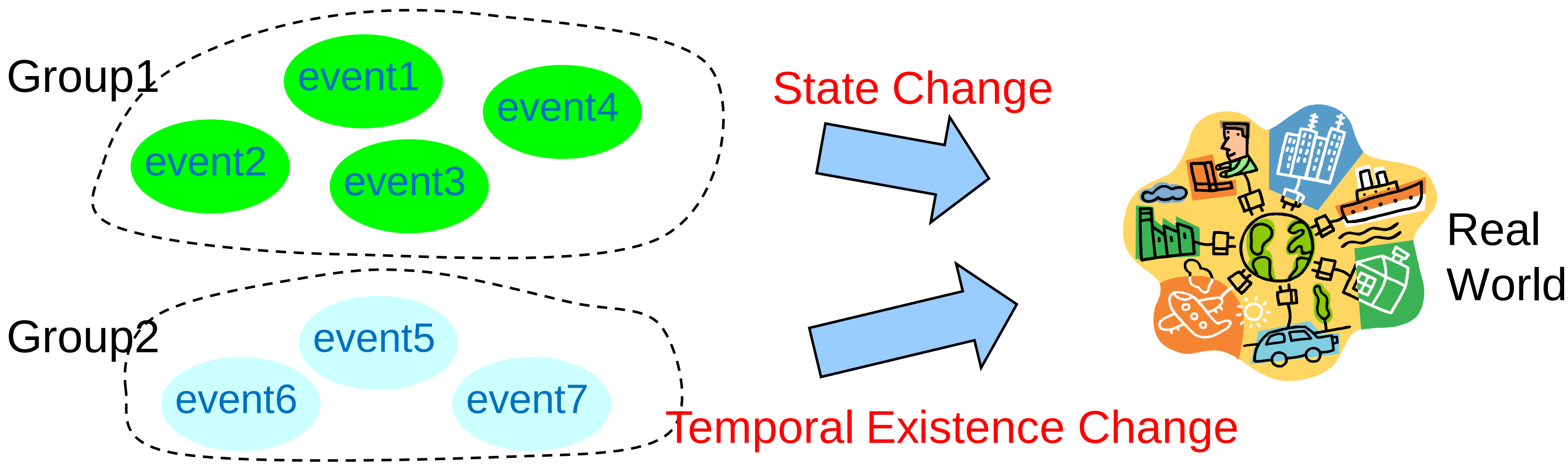
Action3: <AgentGroup,Time,Location>



the argument structures of predicates

Semantic Functions of Events

Logical formulas define what an event acts on or changes in the real world.



Event Semantic Functions

- State Change
- Temporal Existence Change
- Spatial Existence Change
- Cardinality Change
- Comparison
- Object Identification Change

$$F1 \rightarrow \bigcirc F2$$
$$\Box P(\neg E(x) \wedge E(x))$$
$$\neg E(x) \wedge \blacklozenge E(x)$$
$$\exists (i,x) F(x) \rightarrow \bigcirc \exists (>i,x) F(x)$$
$$Value(y) < r$$
$$\exists y (x = y \rightarrow \bigcirc (x \neq y))$$

Example: Semantics Functions

(1) State Change

$$\mathrm{Cure}(x,y) \Leftrightarrow$$
$$\neg \mathrm{Healthy}(y) \wedge (\mathrm{Act}(x,y) \vee \mathrm{Affect}(x,y)) \rightarrow \bigcirc \mathrm{Healthy}(y)$$

"if y is not healthy, and x acts against or affects y, then y will become healthy the next time."

(2) Temporal Existence Change

$$\mathrm{Die}(x) \Leftrightarrow$$
$$\Diamond_P(\Box_P(\neg E(x)) \wedge E(x)) \wedge S(E(x), \neg E(x)) \wedge \Box_F \neg E(x)$$

"x will not exist in the future."

(3) Spatial Existence Change

$$\mathrm{Go}(x) \Leftrightarrow \mathrm{Act}(x) \rightarrow \bigcirc(\neg E(x) \wedge \blacklozenge E(x))$$

"if x acts, then x will not exist here but will exist in some other place."

(4) Cardinality Change

$$\mathrm{Increase}(x) \Leftrightarrow$$
$$\exists i(\mathrm{Nat}(i) \wedge \exists(i,x)\mathrm{Countable}(x) \rightarrow \bigcirc \exists(>i,x)\mathrm{Countable}(x)$$

"if there exist i objects, then there will exist more than i objects the next time."

(5) Comparison

$$\mathrm{High}(x,y) \Leftrightarrow \exists r(\mathrm{Rel}(r) \wedge \mathrm{Value}(x)=r \wedge \mathrm{Value}(y) < r)$$

"the value of x is r, and the value is less than r."

(6) Object Identification Change

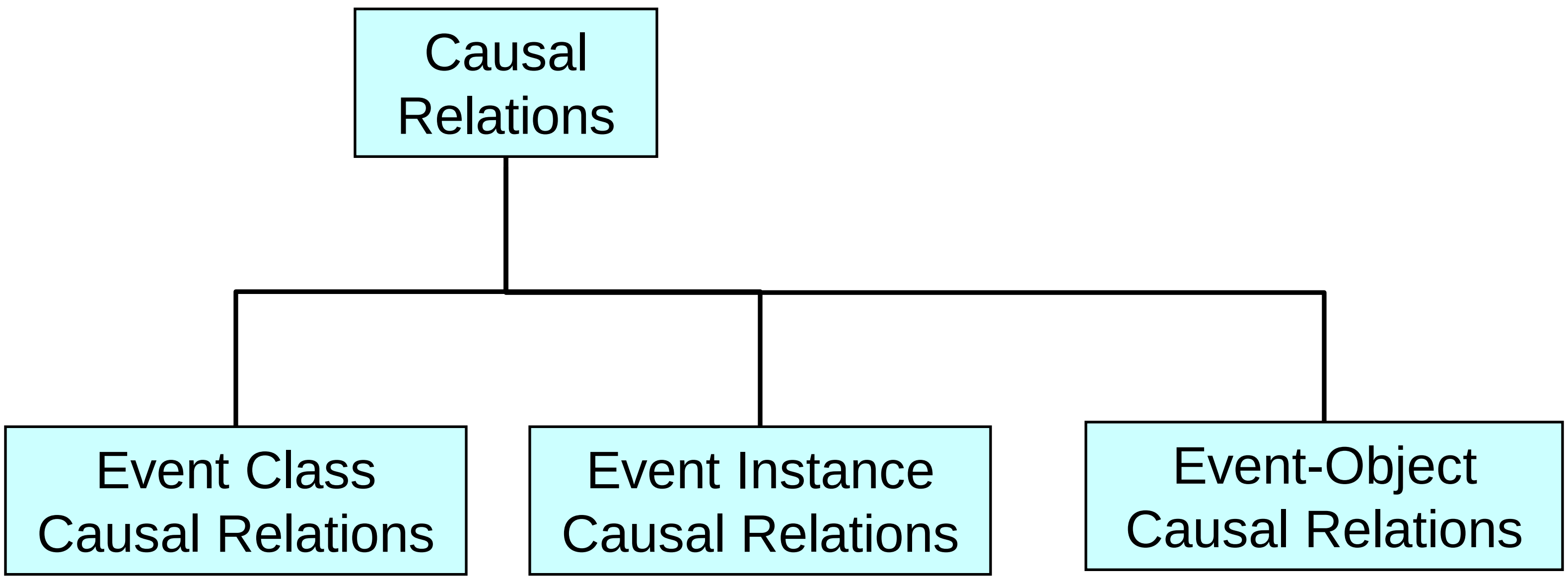
$$\mathrm{Change}(x) \Leftrightarrow \exists y(x=y \rightarrow \bigcirc(x \neq y))$$

"if an object x is identical to y, then the event makes them different the next time."

Binary Relations

Binary Relation

- Object Relation: <Object,Object>
- Event Relation: <Event,Event>
- Causal Relation: <Object ∪ Event,Object ∪ Event >



<Event,Event>

<Event,Object>
<Object,Event>

Event Relations

- Event Relation
  - Event Instance Relation
    - Event Temporal Relation
    - Event Spatial Relation
    - Next Event Relation
    - Instance Part Of Relation
    - Instance Causal Relation
  - Event Class Relation
    - Disjoint Relation
    - Subclass Relation
    - Class Part Of Relation
    - Class Causal Relation

Event Instance Relations

(1) Next Event Relation

$e1 \rightarrow_{next} e2$ if e2 occurs after e1.

(2) Instance Part Of Relation

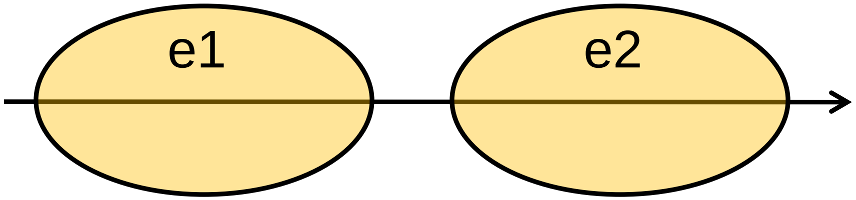
$e1 <_{po} e2$ if e2 temporally includes e1 and e1 occurs in a spatial part of e1.

(3) Instance Causal Relation

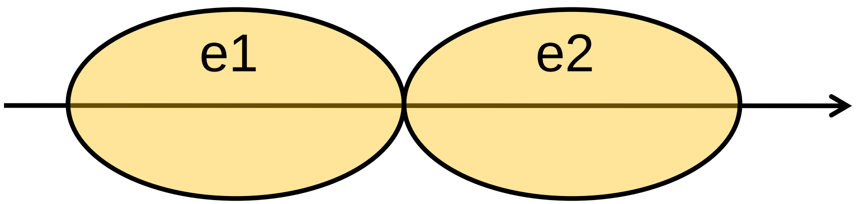
$e1 \rightarrow_{causes} e2$ if e1 causes e2.

Causal Relations over Time

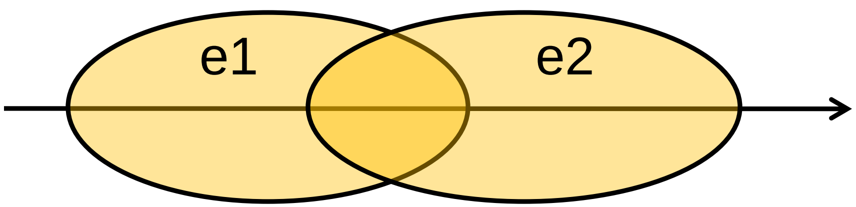
Disjoint causal relation



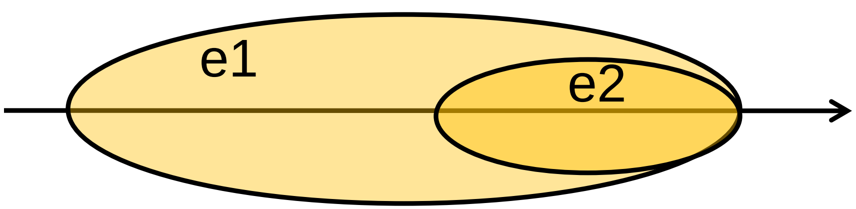
Continuous causal relation



Overlapping causal relation



Partial causal relation



Example:

An earthquake caused a giant tsunami.

A gas explosion destroyed a building.

Heavy rain caused a flood.

Volcanic activity caused a volcanic eruption.

Conclusions

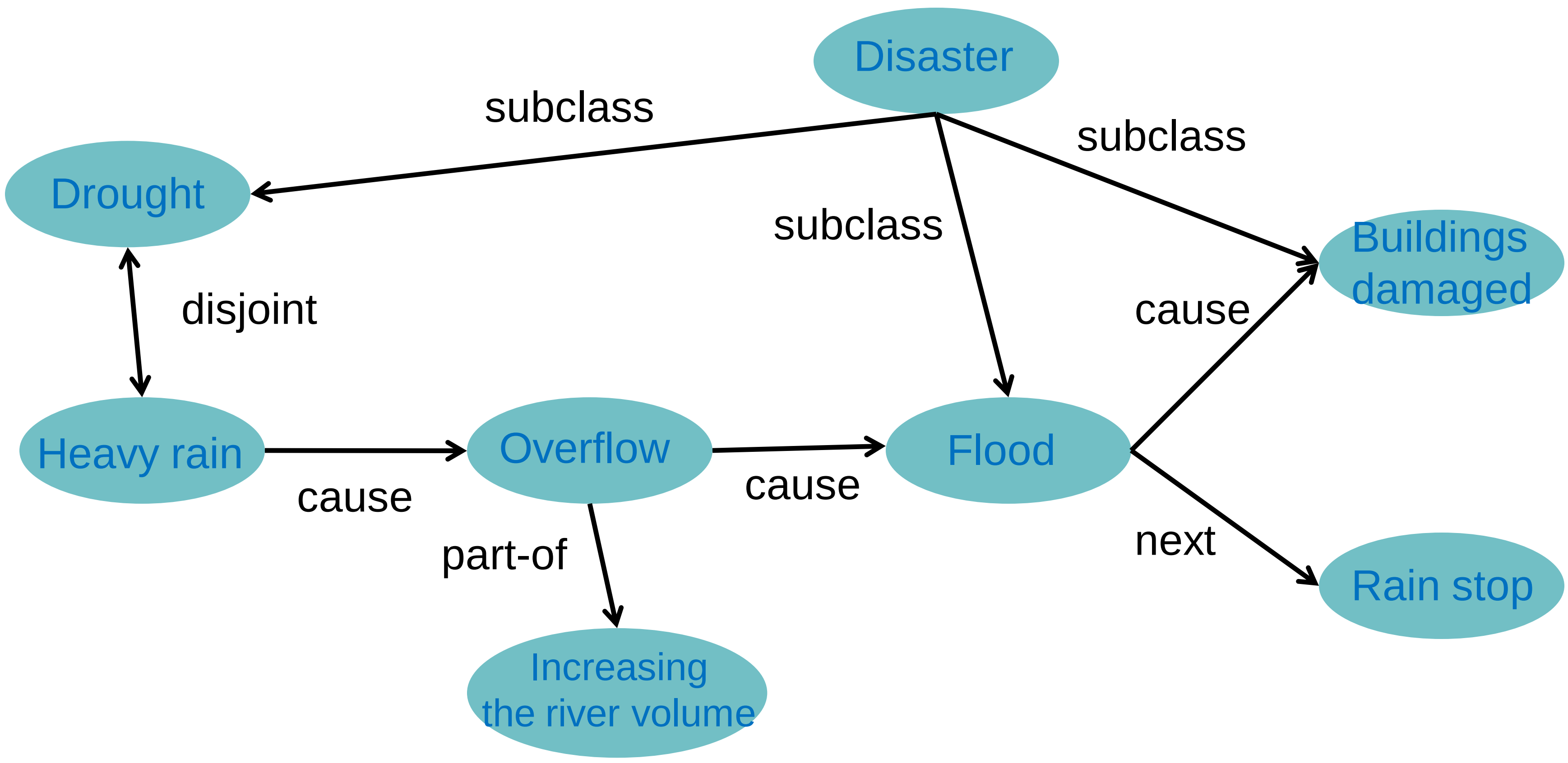
- A classifying event types in an ontology that is based on their component structures.
- A definition of the semantic functions of events, which uses many logical operations in formulas.
- A modification of the event class relations and event instance relations (proposed by Barry Smith).

Future Work

- A logical reasoning system from even relations that derive adds implicit expressions from event knowledge bases if we input event sequences.

- A consistency checking algorithm that finds ontological errors, based on the upper event ontology.

Example: Event Relations



Example: Event Functions

Event predicates	Quantified modal formulas
Cure (x,y)	$\neg$Healthy (y) $\wedge$ (Act (x,y) $\vee$ Affect (x,y)) $\rightarrow$ $\bigcirc$Healthy (y)
Drink (x,y)	(InMouth (y) $\wedge$ Swallow (x,y) $\wedge$ $\neg$Bite (x,y)) $\rightarrow$ $\bigcirc$InBody (y)
Stop (x,y)	Active (y) $\wedge$ (Action (x,y) $\vee$ Affect (x,y)) $\rightarrow$ $\bigcirc\neg$Active (y)
Die (x)	$\Diamond_P$ ($\Box_P \neg$E (x) $\wedge$E (x)) $\wedge$S (E (x) , $\neg$E (x)) $\wedge$ $\Box_F \neg$E (x)
Go (x,y)	Act (x) $\rightarrow$ $\bigcirc$ ($\neg$E (x) $\wedge$ $\blacklozenge$E (x))
BeBorn (x)	$\Box_P$($\neg$E(x)) $\wedge$ E (x)
High (x,y)	$\exists$ r (Rel (r) $\wedge$ Value (x)=r $\wedge$Value (y) $<$ r)
Change (x)	$\exists$ y (x =y $\rightarrow$ $\bigcirc$ (x $\neq$ y))
Increase (x,y)	$\exists$ i (Nat (i) $\wedge$ $\exists$ (i,x) Countable (x) $\rightarrow$ $\bigcirc$ $\exists$ (>i,x) Countable (x)
Make (x,y)	$\exists$ z (Act (x,z) $\rightarrow$ $\bigcirc$(BeBorn(y) $\wedge$ y $\neq$z $\wedge$ Valuable(y))

Event Class Relations

(1) Disjoint Relation

$E1 \parallel E2$ if each instance of E1 and E2 cannot occur simultaneously.

(2) Subclass Relation

$E1 < E2$ if every instance of E1 belongs to E2.

(3) Class Part Of Relation

$E1 <_{po} E2$ if there exists an instance e' of E2 such that $e' <_{po} e$ for every instance e' of E1.

(4) Class Causal Relation

$E1 \rightarrow_{causes} E2$ if there exists an instance e' of E2 such that $e' \rightarrow_{causes} e$ for every instance e' of E1.