Knowledge Representation

Introduction

- So far, we learnt HOW to represent an agent's knowledge base
- Now we focus on WHAT should go into this knowledge base

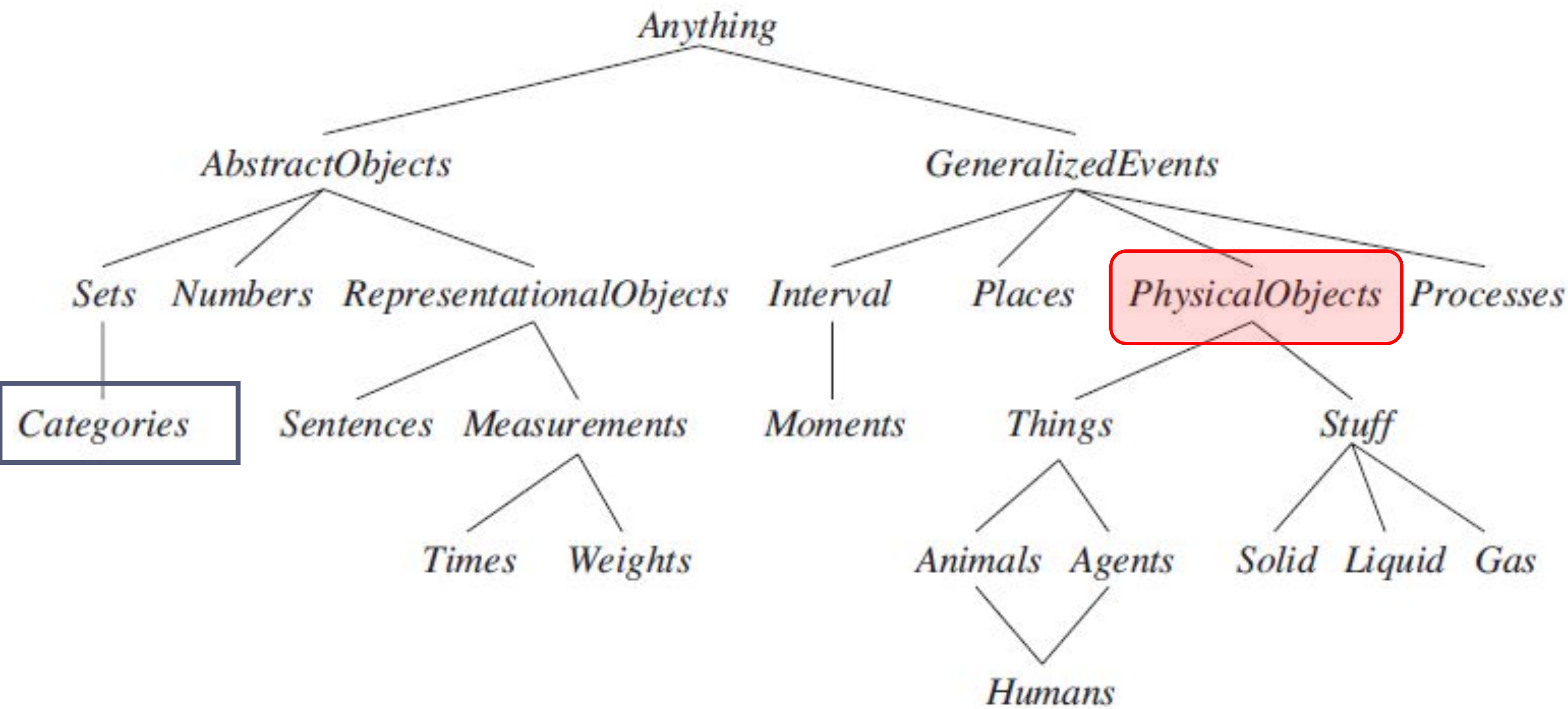
Ontological Engineering

- Concepts in an agent's environment should be properly represented
  - Ontological engineering

Ontology - philosophical study of the nature of being, becoming, existence, or reality, as well as the basic categories of being and their relations

- Can we represent everything in the world?
- Is it necessary to represent everything in the world?
- What we can do is to only describe general concepts
  - An upper (general) ontology
  - Leave place holders to describe specific things
  - Ex. Describe what a 'physical object' is. Specific details of specific objects s.a. television, book, tree,… can be described later

Upper Ontology of the World



Categories and Objects

- We organize objects into categories
- Most of the reasoning takes place at the level of categories

- Agents can
  - Infer the presence of objects from perceptual input
  - Infer the category membership from the perceived properties
  - Use that category information to make predictions about the objects

Categories and Objects

- Representing categories in FOL
  - Predicates e.g. Basketball(b)
  - Objects e.g. Member(b, Basketballs)
- Inheritance

Food
↑
Fruit
↑
Apple

- Subclass relations organize categories into a taxonomy

> Taxonomy - the practice and science of classification

FOL Facts about Categories and Objects

- An object is a member of a category
  - $BB_9 \in$ Basketballs
- A category is a subclass of another category
  - Basketballs $\subset$ Balls
- All members of a category have some property
  - ($x \in$ Basketballs) $\Rightarrow$ Spherical (x)
- Members of a category can be recognized by some properties
  - Orange(x) $\wedge$ Round (x) $\wedge$ Diameter(x)=9.5 $\wedge$ $x \in$ Balls $\Rightarrow$ $x \in$ Basketballs
- A category as a whole has some properties
  - Dogs $\in$ DomesticatedSpecies

FOL Facts about Categories and Objects

- Other relations between categories
  - Disjoint – categories that have no members in common
    - Disjoint({Animals, Vegetables})
  - Exhaustive decomposition - An object must belong to one of the categories
    - ExhaustiveDecomposition({Americans, Canadians, Mexicans}, NorthAmericans)
  - Partition – Disjoint exhaustive decomposition
    - Partition({Males, Females}, Animals)

Physical Composition

- One object can be part of another object
- Thus we define the *PartOf* relation
  - PartOf (Bucharest , Romania)
  - PartOf (Romania, EasternEurope)
  - PartOf (EasternEurope, Europe)
  - PartOf (Europe, Earth)
- PartOf relation is transitive and reflexive
  - $PartOf(x, y) \land PartOf(y, z) \Rightarrow PartOf(x, z)$
  - $PartOf(x, x)$

Physical Composition

- Composite object categories can be characterized by structural relations among parts
  - $Biped(a) \Rightarrow \exists l_1, l_2, b\ Leg(l_1) \wedge Leg(l_2) \wedge Body(b) \wedge PartOf(l_1, a) \wedge PartOf(l_2, a) \wedge PartOf(b, a) \wedge Attached(l_1, b) \wedge Attached(l_2, b) \wedge l_1 \neq l_2 \wedge [\forall l_3\ Leg(l_3) \wedge PartOf(l_3, a) \Rightarrow (l_3 = l_1 \vee l_3 = l_2)]$

- PartPartition – an object is composed of parts in its PartPartition

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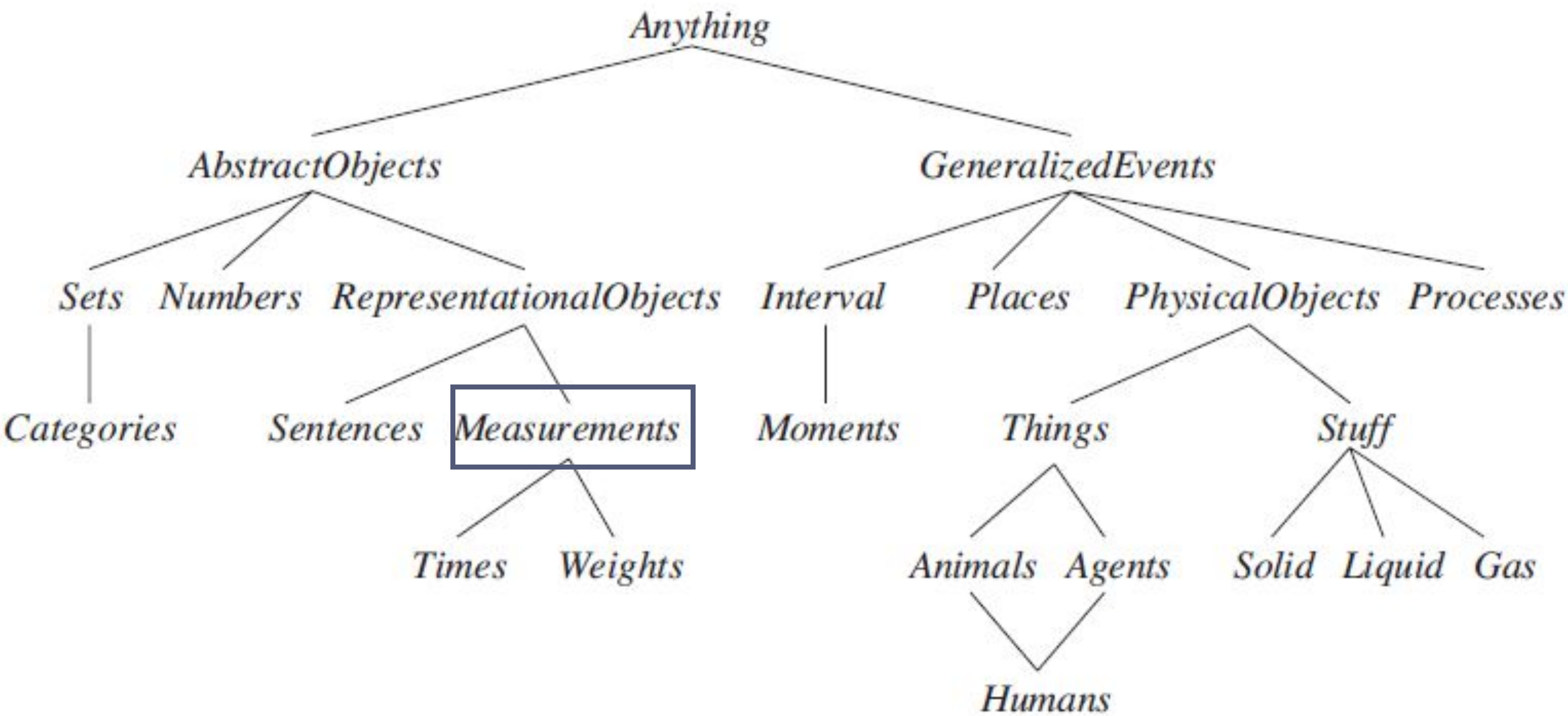
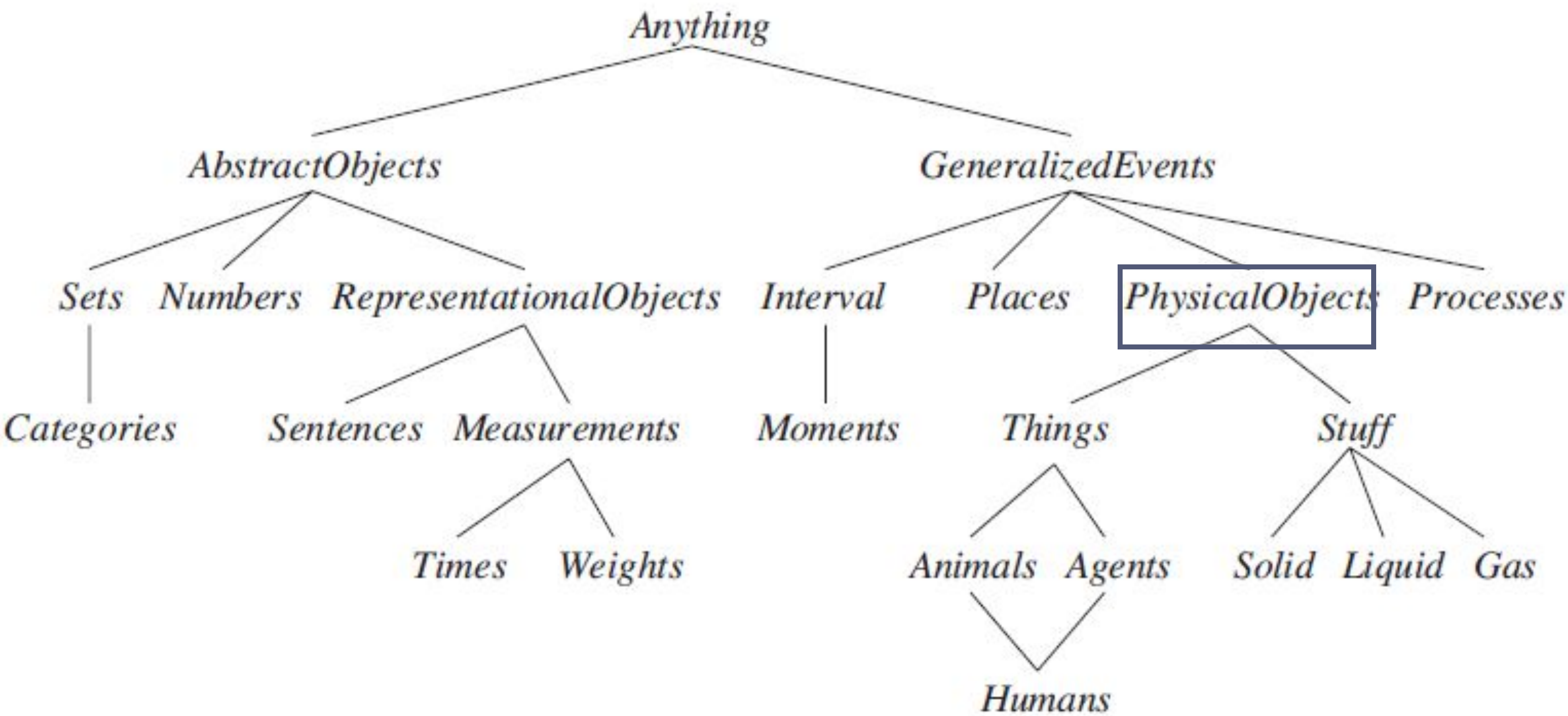


Measurements

- Some objects have height, length, mass, cost, etc
- Measures – values we assign to these properties
- We define abstract "measure objects"
  - Same measure object can have different names
  - Length(L_1)=Inches(1.5)=Centimeters(3.81)
- Quantitative measures are easy to represent
- How about measures with no agreed scale or value?
  - Poems have beauty
  - Curries have spiciness
  - Exercises have difficulty
- Objects can be ordered by these measures

Upper Ontology of the World



Substances and Objects

- Things vs stuff
  - Cat vs butter
- Count nouns and mass nouns
- How to represent stuff?
  - $b \in Butter \land PartOf(p, b) \Rightarrow p \in Butter$
- Butter vs PoundOfButter
- Intrinsic properties – properties that belong to the very substance of the object
  - Colour, melting point, density
- Extrinsic – properties of objects. Not retained under subdivision
  - Height, weight, length, shape

Substances and Objects

- Substance (mass noun)– object definition contains only intrinsic properties
- Object (count noun)– definition contains any extrinsic properties
- Stuff – most general substance category
- Thing – most general discrete object category

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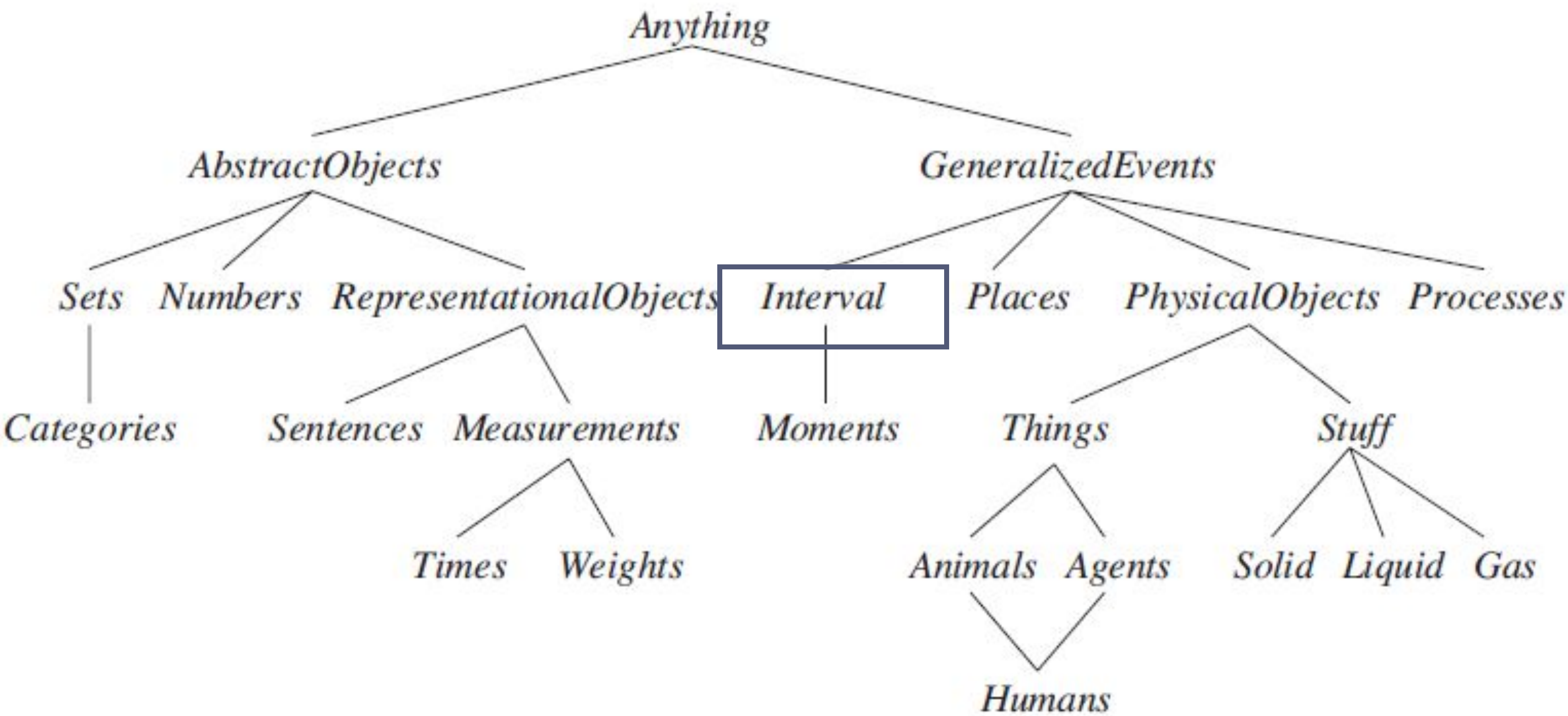


Time and Event Calculus

- Action – Any logical term
  - Forward, Turn(Right)
  - Should recognize which agent is doing the action
- Fluents – functions and predicates that vary across time
- Atemporal (eternal) predicates and functions
  - Gold(G_1)

Calculus - the mathematical study of change

Time and Event Calculus

- When there are multiple agents, actions have durations, and can overlap with each other….
- Event calculus to the rescue
  - Fluents hold at points in time
  - Reasoning is done over intervals of time
- T – the predicate that is used to assert that a fluent is actually true at some point in time
  - T(At(Shiva , Colombo), t)
- T can be extended to work over intervals
  - $T(f, (t1, t2)) \Leftrightarrow [\forall\ t\ (t1 \leq t < t2) \Rightarrow T(f, t)]$
- Events can be described as instances of event categories
  - $E1 \in$ Flyings(Shiva , Colombo, Jaffna)

Time and Event Calculus

- Event calculus predicates
  - **T(f, t)** Fluent f is true at time t
  - **Happens(e, i)** Event e happens over the time interval i
  - **Initiates(e, f, t)** Event e causes fluent f to start to hold at time t
  - **Terminates(e, f, t)** Event e causes fluent f to cease to hold at time t
  - **Clipped(f, i)** Fluent f ceases to be true at some point during time interval i
  - **Restored (f, i)** Fluent f becomes true sometime during time interval i

Time and Event Calculus

- Event calculus axioms
  - Happens(e, (t1, t2)) $\land$ Initiates(e, f, t1) $\land$ $\neg$Clipped(f, (t1, t)) $\land$ t1 < t $\Rightarrow$ T(f, t)
  - Happens(e, (t1, t2)) $\land$ Terminates(e, f, t1) $\land$ $\neg$Restored (f, (t1, t)) $\land$ t1 < t $\Rightarrow$ $\neg$T(f, t)
  - Clipped(f, (t1, t2)) $\Leftrightarrow$ $\exists$ e, t, t3 Happens(e, (t, t3)) $\land$ t1 $\leq$ t < t2 $\land$ Terminates(e, f, t)
  - Restored (f, (t1, t2)) $\Leftrightarrow$ $\exists$ e, t, t3 Happens(e, (t, t3)) $\land$ t1 $\leq$ t < t2 $\land$ Initiates(e, f, t)

Processes

- AKA liquid events
- Different from discrete events
- Analogous to the difference between substances and objects
- Any subinterval of a process is also a member of the same process category
  - $(e \in Processes) \land Happens(e, (t1, t4)) \land (t1 < t2 < t3 < t4) \Rightarrow Happens(e, (t2, t3))$

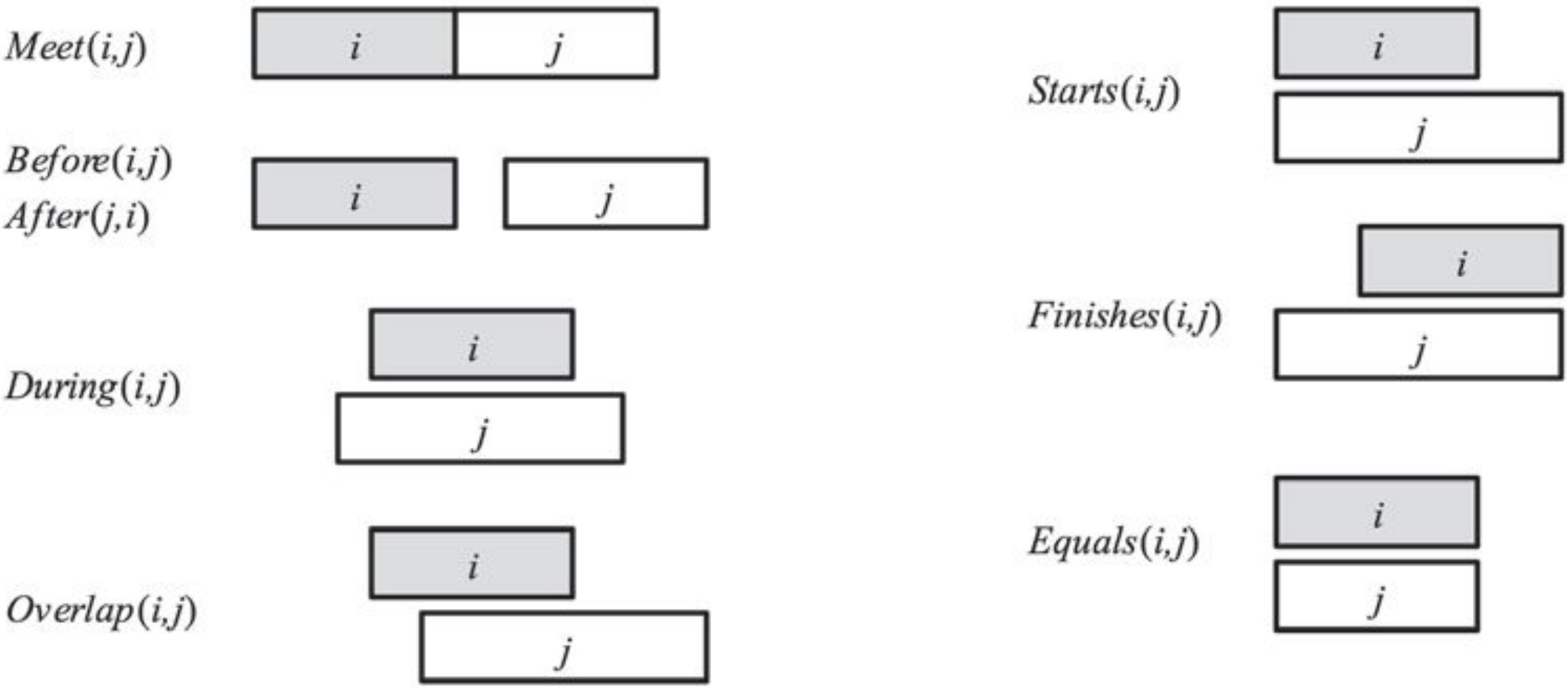
Intervals

- Two types
  - **Moments** –have zero duration
  - **Extended intervals**
  - Partition({Moments,ExtendedIntervals}, Intervals)
  - $i \in Moments \Leftrightarrow Duration(i)=Seconds(0)$
- Moments are points in a time scale
  - Time – Function that delivers the point on the time scale for a moment
  - Begin – function that delivers the earliest moment in an interval
  - End– function that delivers the latest moment in an interval
  - Duration – function that delivers the difference between the end time and the start time

Intervals

- Allen's interval relations
  - Meet, Before, After, During, Overlap, Begins, Finishes, Equals
  - Meet(i, j) $\Leftrightarrow$ End(i)=Begin(j)
  - Before(i, j) $\Leftrightarrow$ End(i) < Begin(j)
  - After (j, i) $\Leftrightarrow$ Before(i, j)
  - During(i, j) $\Leftrightarrow$ Begin(j) < Begin(i) < End(i) < End(j)
  - Overlap(i, j) $\Leftrightarrow$ Begin(i) < Begin(j) < End(i) < End(j)
  - Begins(i, j) $\Leftrightarrow$ Begin(i) = Begin(j)
  - Finishes(i, j) $\Leftrightarrow$ End(i) = End(j)
  - Equals(i, j) $\Leftrightarrow$ Begin(i) = Begin(j) $\wedge$ End(i) = End(j)

Intervals



Meet(i,j)
i
j
Before(i,j)
After(j,i)
i
j
During(i,j)
i
j
Overlap(i,j)
i
j
Starts(i,j)
i
j
Finishes(i,j)
i
j
Equals(i,j)
i
j

Mental Events and Mental Objects

- Now our agents can have beliefs and infer new beliefs
- But they have no knowledge about beliefs or about deductions
- Now what we need is a model of
  - The mental objects that are in a KB
  - The mental processes that manipulate those mental objects

Mental Events and Mental Objects

- Describes the relationship between agents and mental objects
  - Propositional attitudes
  - Believes, Knows, Wants, Intends, Informs
    - Believes(Lois, Flies(Superman))
- (Superman = Clark) $\wedge$ Knows(Lois , CanFly(Superman)) $\models$ Knows(Lois, CanFly(Clark))
- propositional attitudes like *believes and knows,* have **referential opacity**
- **Referential transparency**
  - 2 + 2 = 4
  - 4 < 5
  - 2 + 2 < 5