PROV: The W3C PROVenance model

Tutorial plan -- 1.5 hours

Part I: The PROV Data Model and PROV Notation (PROV-N)

Part II: Constraints of the Provenance Model

Part III: Known extensions and applications

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EDBT 2013, March 20, 2013

PROV: The W3C PROVenance model

Part I of III
The PROV Data Model

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Provenance Metadata

Provenance refers to the sources of information, including entities and processes, involving in producing or delivering an artifact (*)

Provenance is a description of how things came to be, and how they came to be in the state they are in today (*)

- Data dependencies -- from process or other data
- Activities that operate on data, and their temporal relationships
- Data integration: which fragments come from which source
- Who played what role in creating the data (responsibilities)
- ...

(*) Definitions proposed by the W3C Incubator Group on provenance:
http://www.w3.org/2005/Incubator/prov/wiki/What_Is_Provenance

Why does provenance matter?

- To establish quality, relevance, trust
- To track information attribution through complex transformations
- To describe one's experiment to others, for understanding / reuse
- To provide evidence in support of scientific claims
- To enable *post hoc* process analysis for debugging, improvement, evolution

...in such areas as:

- Open Information Systems
  - origin of the data, who was responsible for its creation
- Science applications
  - how the results were obtained
- News
  - origins and references of blogs, news items
- Law
  - licensing attribution of documents, data
  - privacy information

Provenance is not a new subject (*)

- There has been lot of work around
  - workflow systems
  - databases
  - knowledge representation
  - information retrieval
- Existing community-grown vocabularies
  - Open Provenance Model (OPM)
  - Dublin Core
  - Provenir ontology
  - Provenance vocabulary
  - SWAN provenance ontology
  - etc.

(*) source: Paul Groth, 2012 http://www.w3.org/2011/prov/wiki/ISWCProvTutorial

The W3C Working Group on Provenance: timeline

http://www.w3.org/2011/prov/wiki/

2009-2010

W3C
Incubator group
on provenance

Chair: Yolanda Gil,
ISI, USC

Main output:
"Provenance XG Final Report"
http://www.w3.org/2005/Incubator/prov/XGR-prov/
- provides an overview of the various existing approaches, vocabularies
- proposes the creation of a dedicated W3C Working Group

April, 2011

W3C
working group
approved

Chairs:
Luc Moreau,
Paul Groth

April, 2013

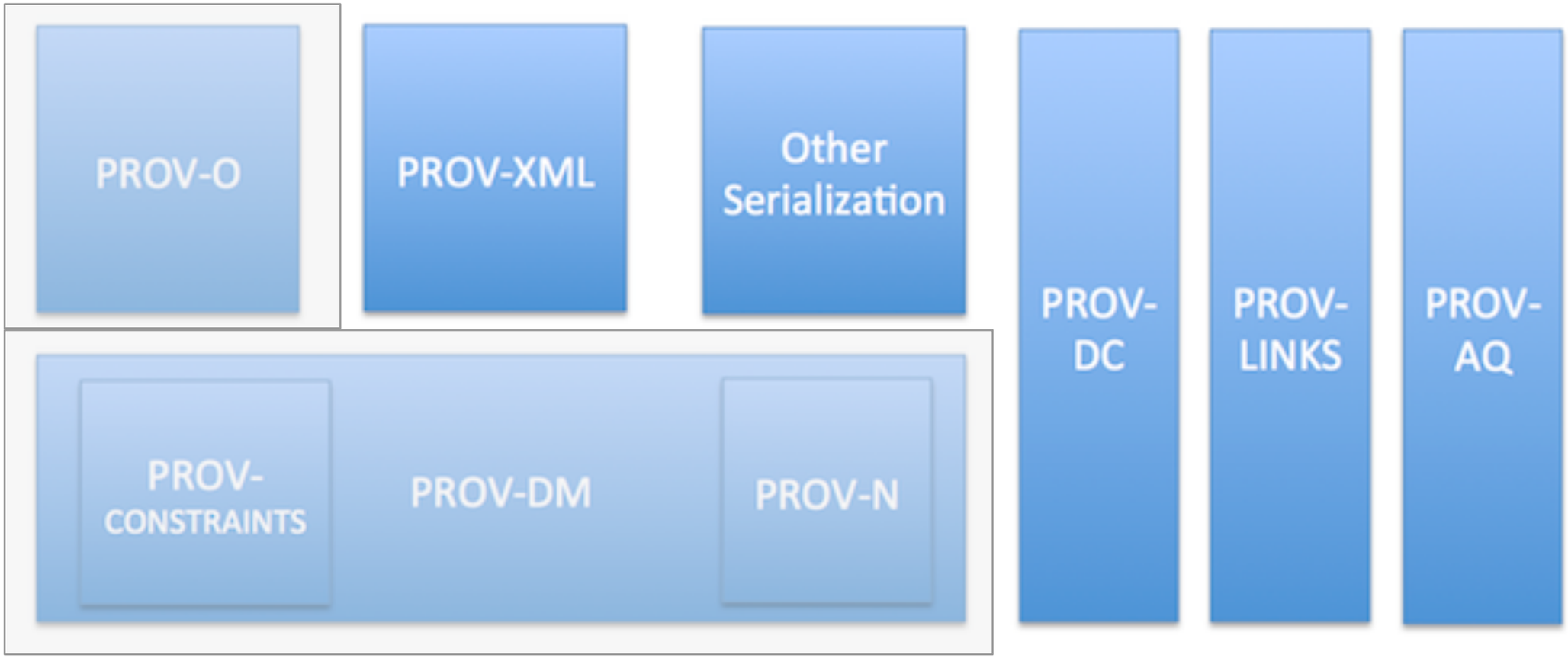
Proposed
Recommendations
finalised

prov-dm: Data Model
prov-o: OWL ontology, RDF encoding
prov-n: prov notation
prov-constraints

...plus a number of non-prescriptive Notes

PROV: scope and structure

Recommendation track

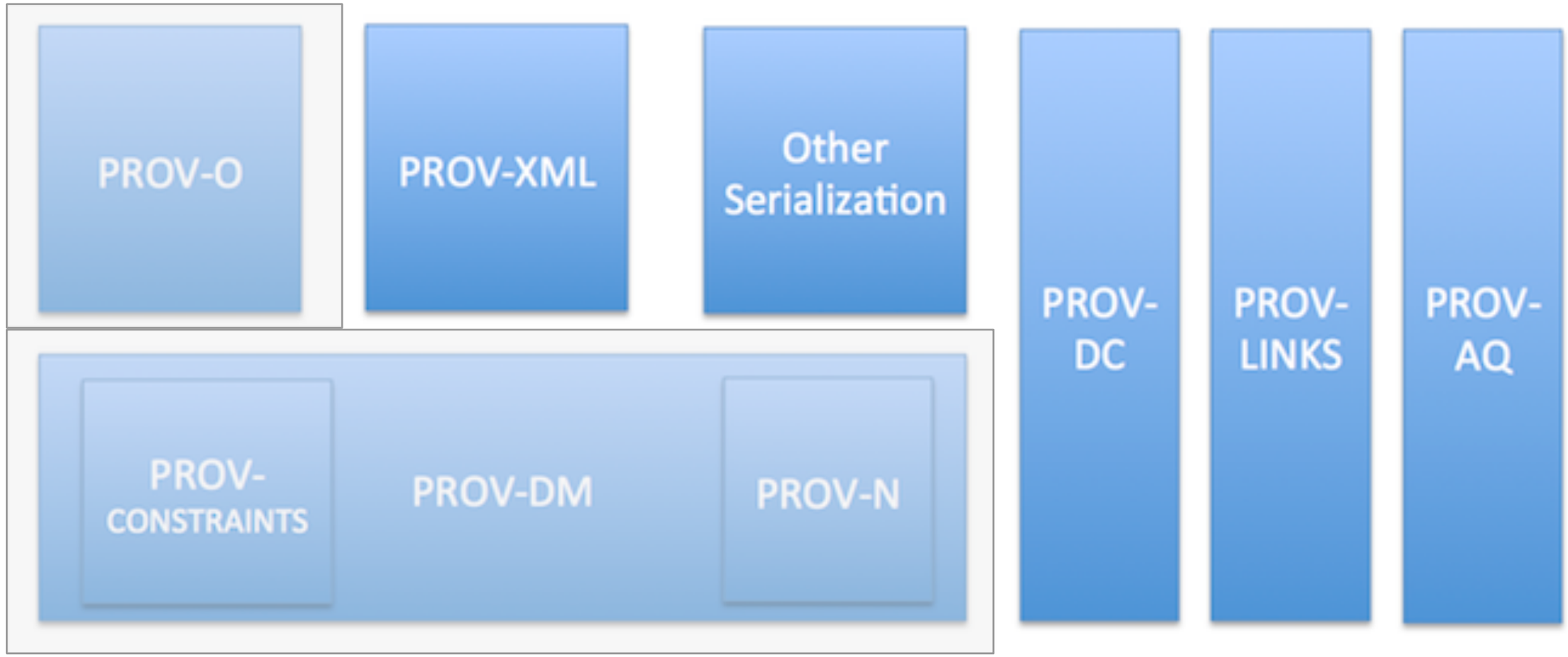


plus: Prov-dictionary

source: http://www.w3.org/TR/prov-overview/

PROV: scope and structure

Recommendation track



plus: Prov-dictionary

This tutorial

source: http://www.w3.org/TR/prov-overview/

PROV: scope and structure

Recommendation track

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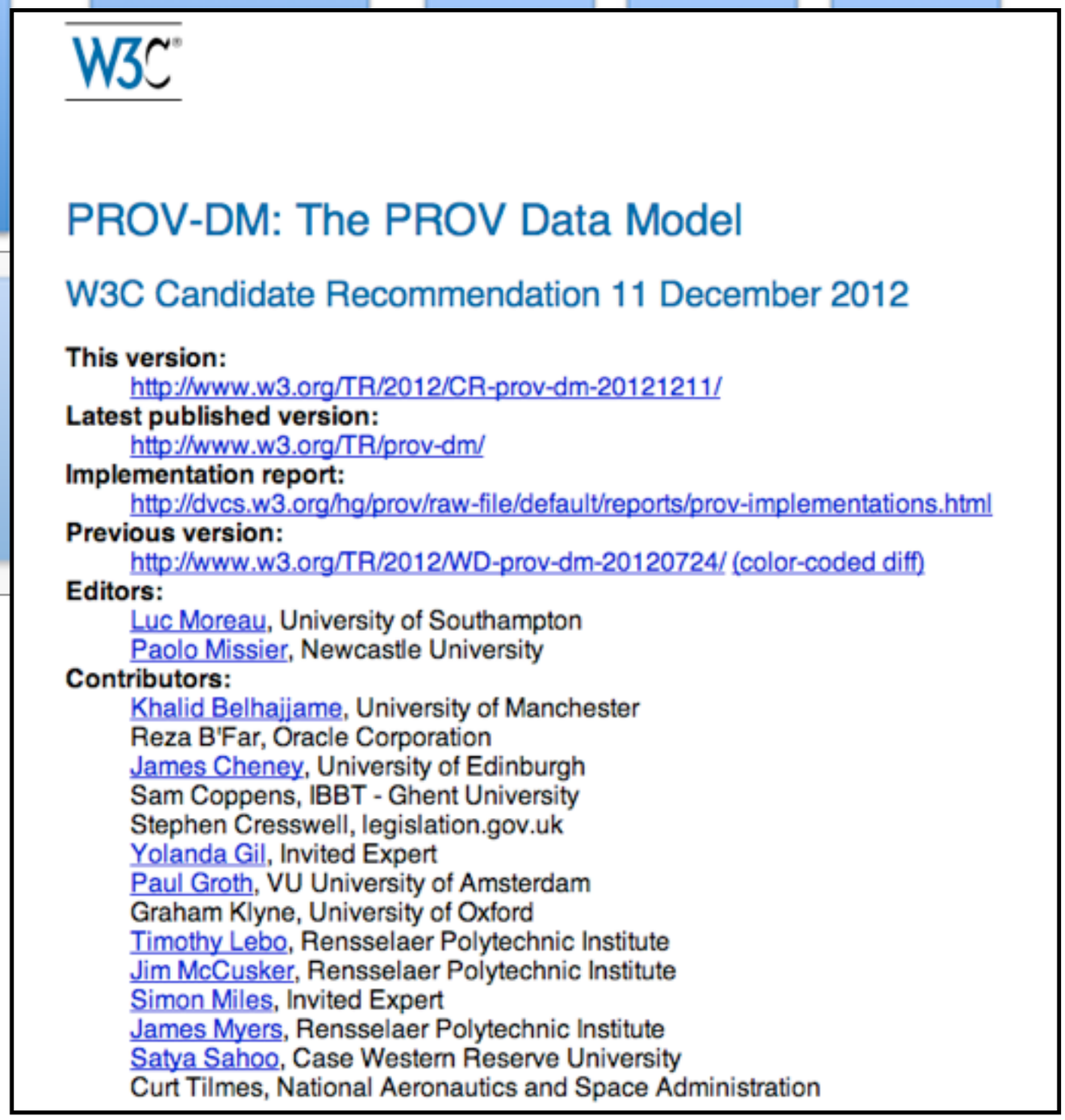
This tutorial



W3C

PROV-DM: The PROV Data Model

W3C Candidate Recommendation 11 December 2012

This version:
http://www.w3.org/TR/2012/CR-prov-dm-20121211/
Latest published version:
http://www.w3.org/TR/prov-dm/
Implementation report:
http://dvcs.w3.org/hg/prov/raw-file/default/reports/prov-implementations.html
Previous version:
http://www.w3.org/TR/2012/WD-prov-dm-20120724/ (color-coded diff)
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Simon Miles, Invited Expert
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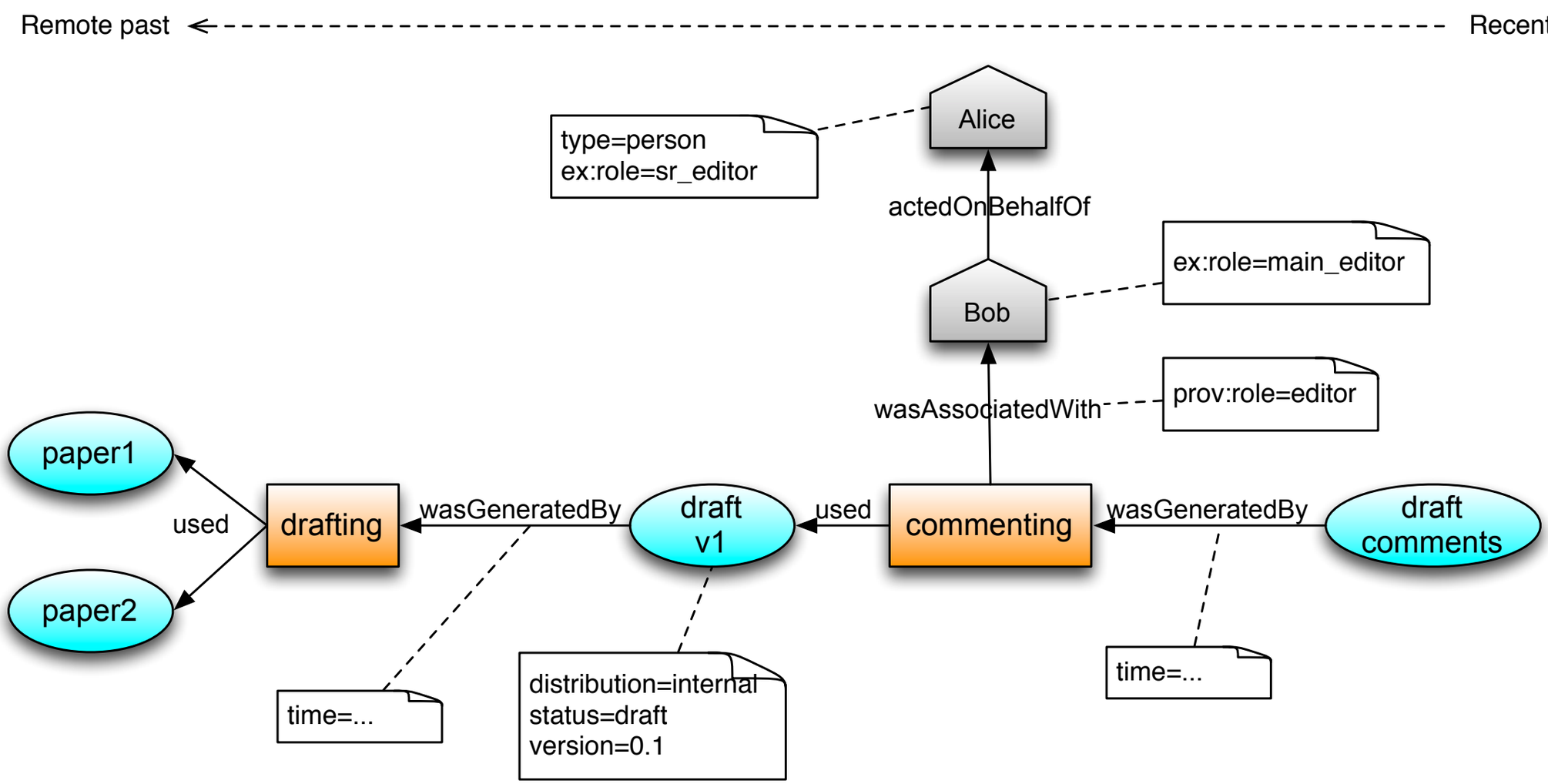
Satya Sahoo, Case Western Reserve University
Curt Tilmes, National Aeronautics and Space Administration

source: http://www.w3.org/TR/prov-overview/

PROV Core Elements (graph depiction)



Entity

*An **entity** is a physical, digital, conceptual, or other kind of thing **with some fixed aspects**; entities may be real or imaginary.*

Activity

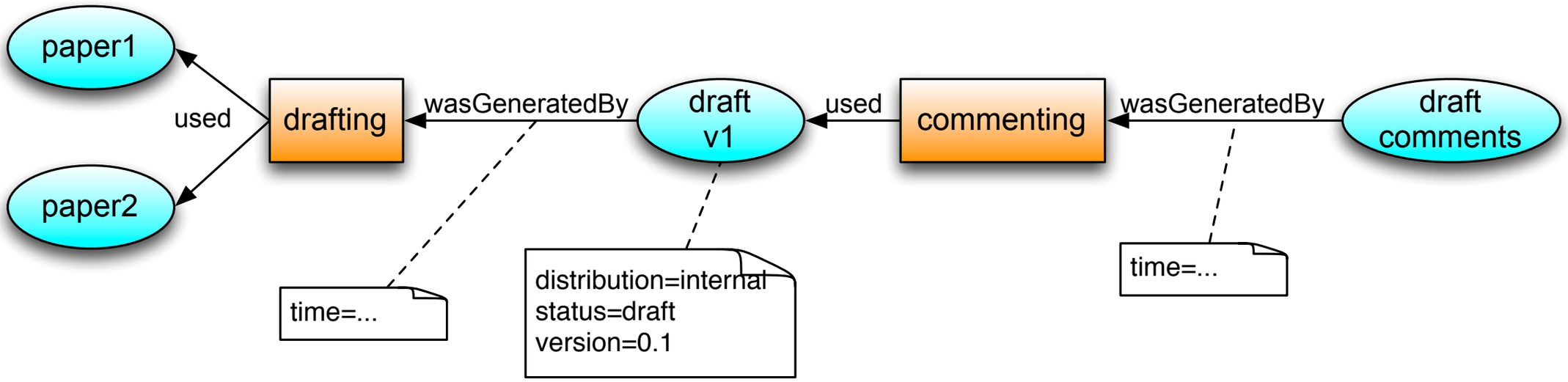
*An **activity** is something that occurs over a period of time and acts upon or with entities; it may include consuming, processing, transforming, ..., **using, or generating** entities.*

Agent

*An **agent** is something that bears some form of responsibility for an activity taking place, for the existence of an entity, or for another agent's activity.*

Jump to alternate

Generation, Usage



Generation *is the* ***completion of production*** *of a new entity by an activity. This entity did not exist before generation and becomes available for usage after this generation.*

Usage *is the* ***beginning of utilizing*** *an entity by an activity. Before usage, the activity had not begun to utilize this entity*

PROV is based on a notion of ***instantaneous event***s, that mark transitions in the world

- generation, usage (and others)

Ordering constraints amongst events: **-- see part II of this tutorial**

“generation of e must precede each of usages”

“a can only use / generate e after it has started and before it has ended”

Concepts and relations

Generation of “draft v1” expressed as relation:

wasGeneratedBy(“draft v1”, ...)

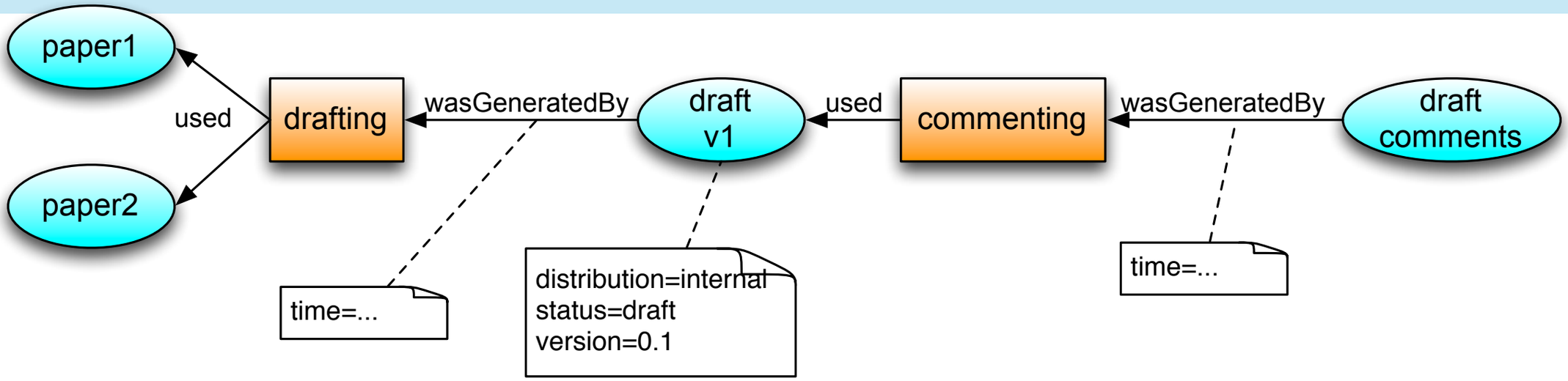
Usage of “draft v1” by “commenting” expressed as relation:

used(“commenting, “draft v1”,...)

Table 2◊: Mapping of PROV core concepts to types and relations

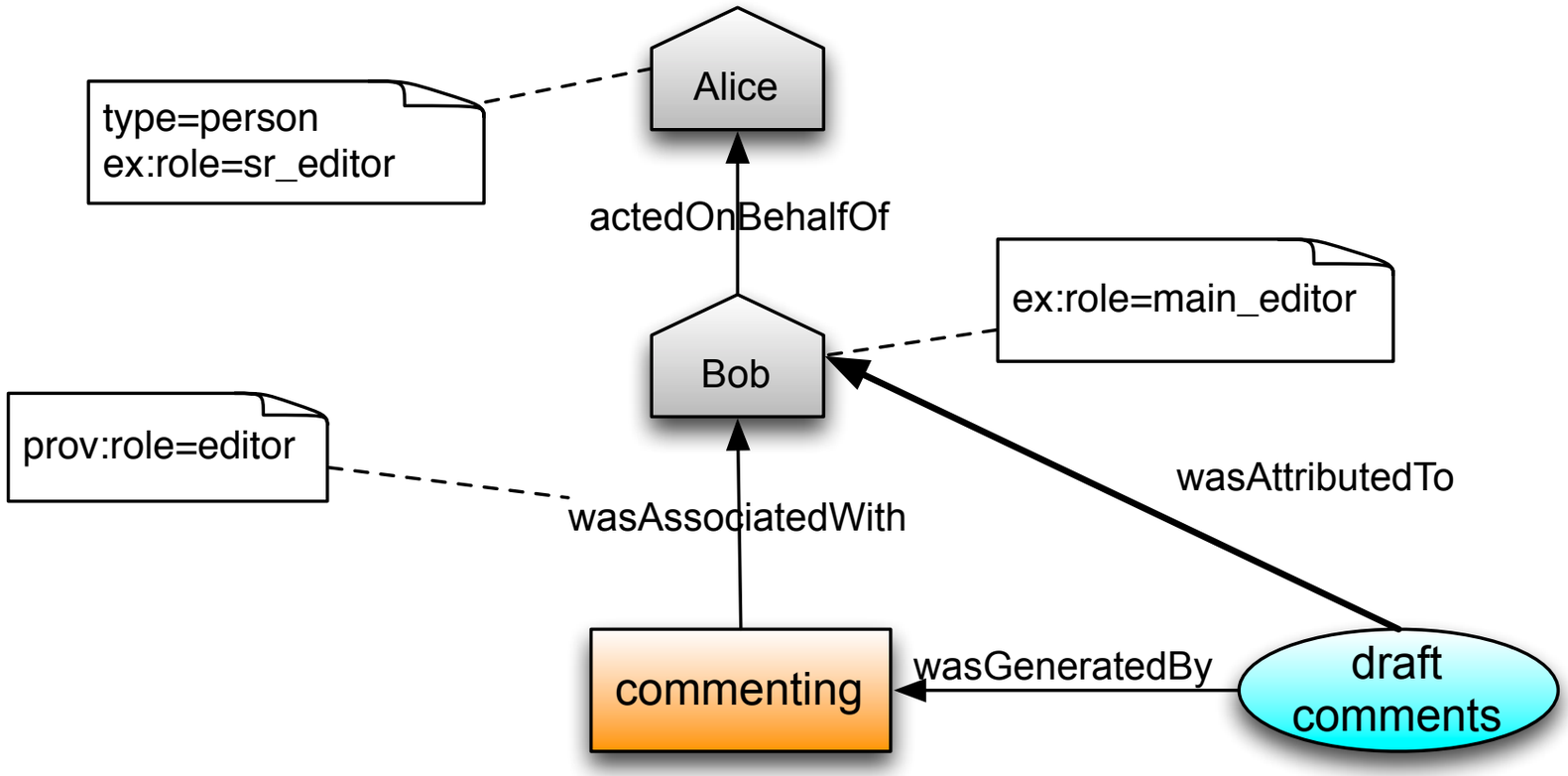
PROV Concepts	PROV-DM types or relations	Name	Overview
Entity	PROV-DM Types	Entity	Section 2.1.1
Activity		Activity	Section 2.1.1
Agent		Agent	Section 2.1.3
Generation	PROV-DM Relations	WasGeneratedBy	Section 2.1.1
Usage		Used	Section 2.1.1
Communication		WasInformedBy	Section 2.1.1
Derivation		WasDerivedFrom	Section 2.1.2
Attribution		WasAttributedTo	Section 2.1.3
Association		WasAssociatedWith	Section 2.1.3
Delegation		ActedOnBehalfOf	Section 2.1.3

PROV notation




```
document

prefix prov <http://www.w3.org/ns/prov#>
prefix ex <http://www.example.com/>

entity(ex:draftComments)
entity(ex:draftV1, [ ex:distr='internal', ex:status = "draft"])
entity(ex:paper1)
entity(ex:paper2)

activity(ex:commenting)
activity(ex:drafting)
wasGeneratedBy(ex:draftComments, ex:commenting, 2013-03-18T11:10:00)
used(ex:commenting, ex:draftV1, -)
wasGeneratedBy(ex:draftV1, ex:drafting, -)
used(ex:drafting, ex:paper1, -)
used(ex:drafting, ex:paper2, -)

endDocument
```

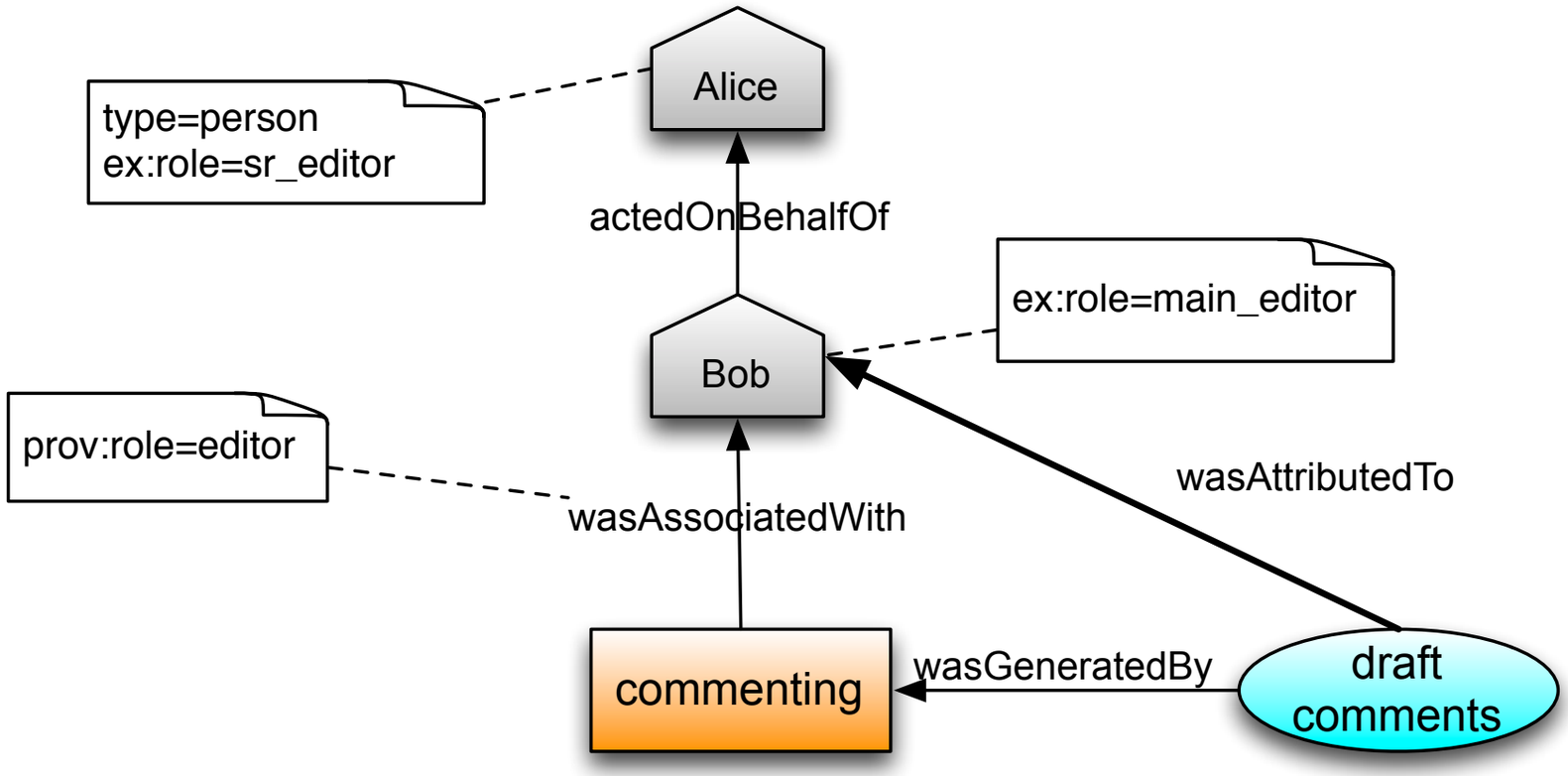
Association, Attribution, Delegation: who did what?



*An activity **association** is an assignment of responsibility to an agent for an activity, indicating that the agent had a role in the activity.*

***Attribution** is the ascribing of an entity to an agent.*

Association, Attribution, Delegation: who did what?



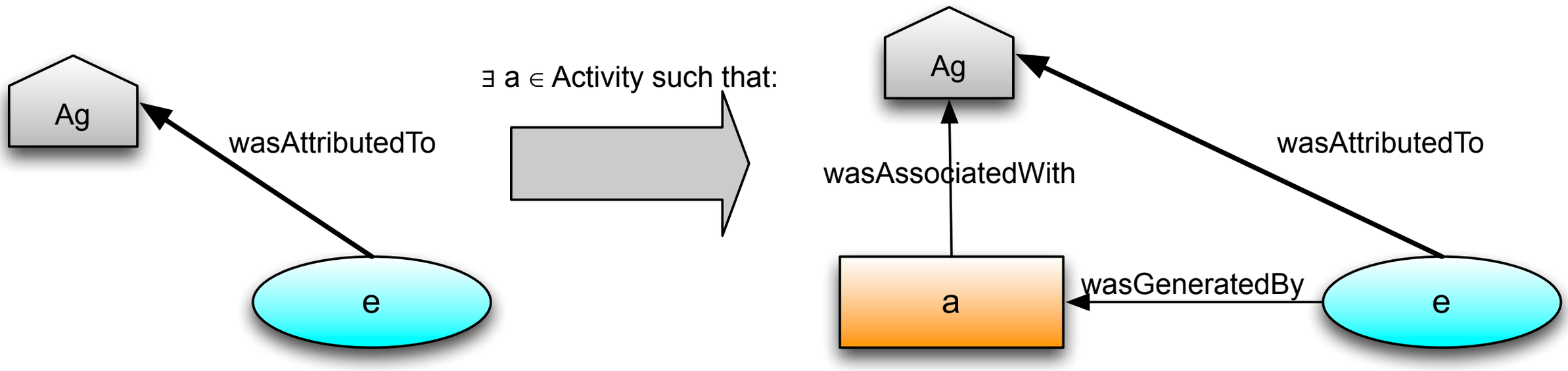
*An activity **association** is an assignment of responsibility to an agent for an activity, indicating that the agent had a role in the activity.*

***Attribution** is the ascribing of an entity to an agent.*

```
entity(ex:draftComments, [ ex:distr='internal' ])
activity(ex:commenting)
agent(ex:Bob,   [prov:type = "mainEditor"] )
agent(ex:Alice, [prov:type = "srEditor"])

wasAssociatedWith(ex:commenting, Bob, -, [prov:role = "editor"])
actedOnBehalfOf(Bob, Alice)
wasAttributedTo(ex:draftComments, ex:Bob)
```

Association and Attribution

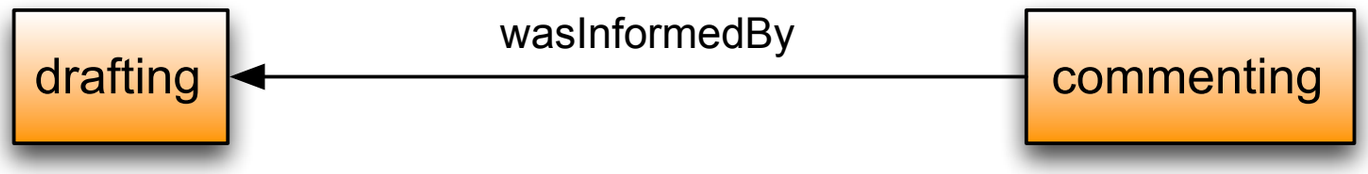
Q.: what is the relationship between attribution and association?



This is inference rule 13 in the PROV-CONSTR document
See part II of this tutorial

```
entity(e)
agent(Ag)
activity(a)

wasAttributedTo(e, Ag)
wasGeneratedBy(e, a)
wasAssociatedWith(a, Ag)
```

Communication amongst activities

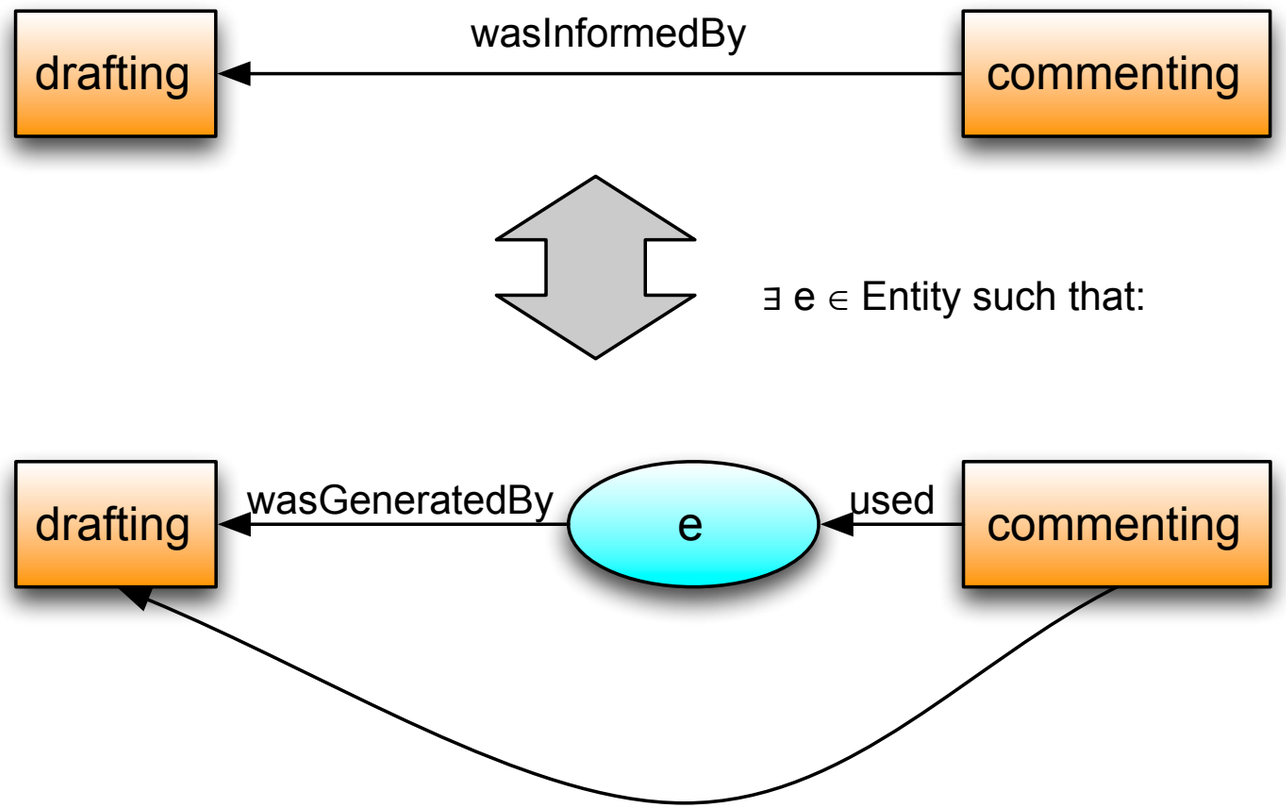


Communication *is the exchange of some unspecified entity by two activities, one activity using some entity generated by the other.*

```
activity(ex:commenting)
activity(ex:drafting)

wasInformedBy(ex:commenting, ex:drafting)
```

Communication, generation, usage

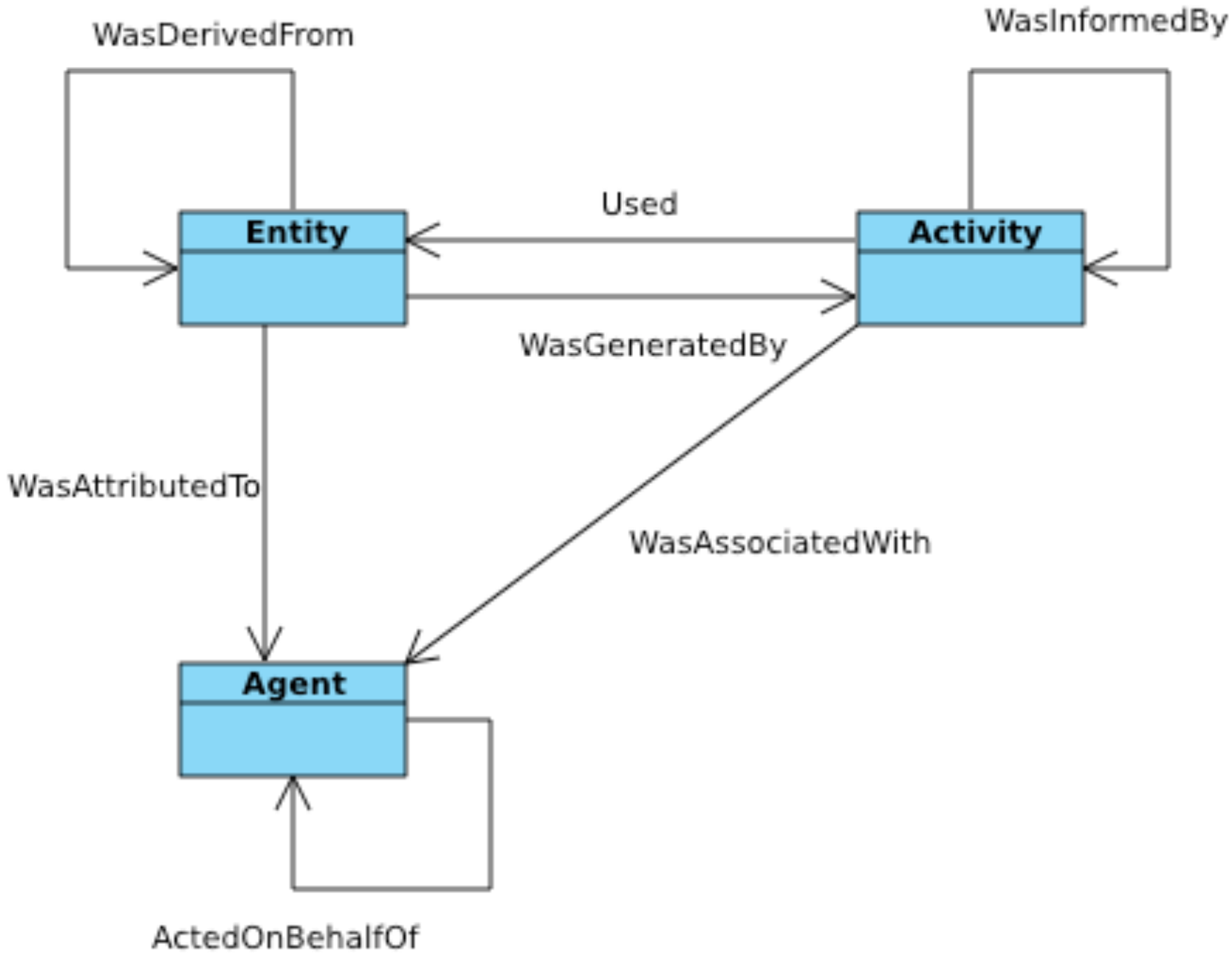
Q.: what is the relationship between communication, generation, and usage?




```
activity(ex:commenting)
activity(ex:drafting)
entity(e)
wasInformedBy(ex:commenting, ex:drafting)
wasGeneratedBy(e,ex:drafting)
used(ex:commenting, e)
```

This are inference rules 5 and 6 in the PROV-CONSTR document

Summary of the PROV Core model



Derivation amongst entities

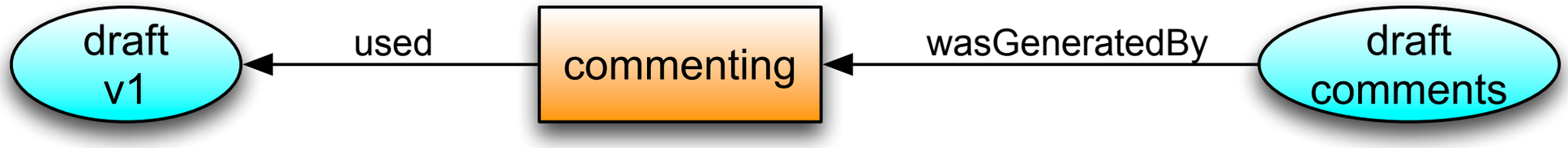
*A **derivation** is a transformation of an entity into another, an update of an entity resulting in a new one, or the construction of a new entity based on a pre-existing entity.*

```
entity(ex:draftV1)
entity(ex:draftV2)
wasDerivedFrom(ex:draftComments, ex:draftV1)
```

Q.: what is the relationship between derivation, generation, and usage?

Relations may be given identifiers

Relation IDs make it possible to refer to relations in other relations




```
entity(ex:draftComments)
entity(ex:draftV1)
activity(ex:commenting)
wasGeneratedBy(gen1; ex:draftComments, ex:commenting, -)
used(use1; ex:commenting, ex:draftV1, -)
```

gen1 denotes a generation event

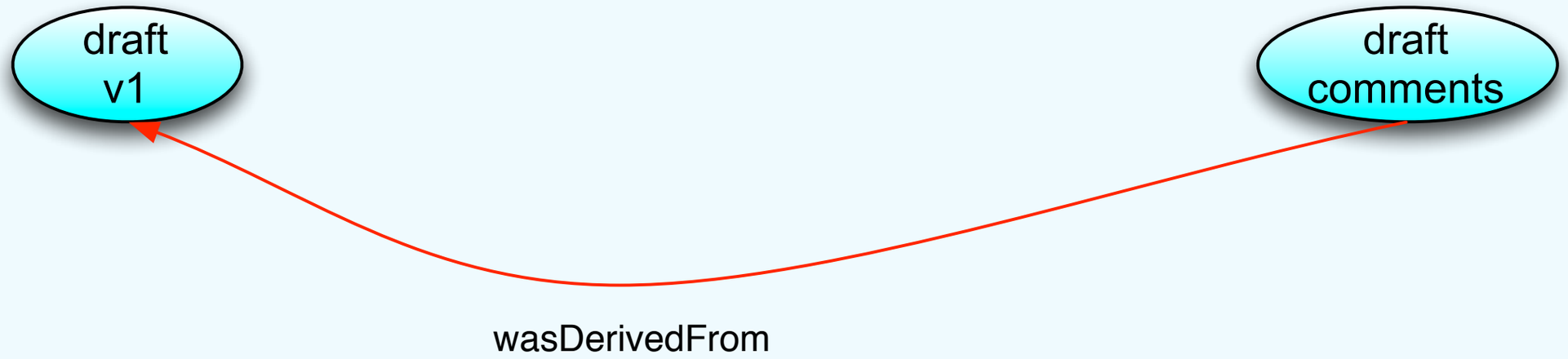
use1 denotes a usage event

General derivation relation:

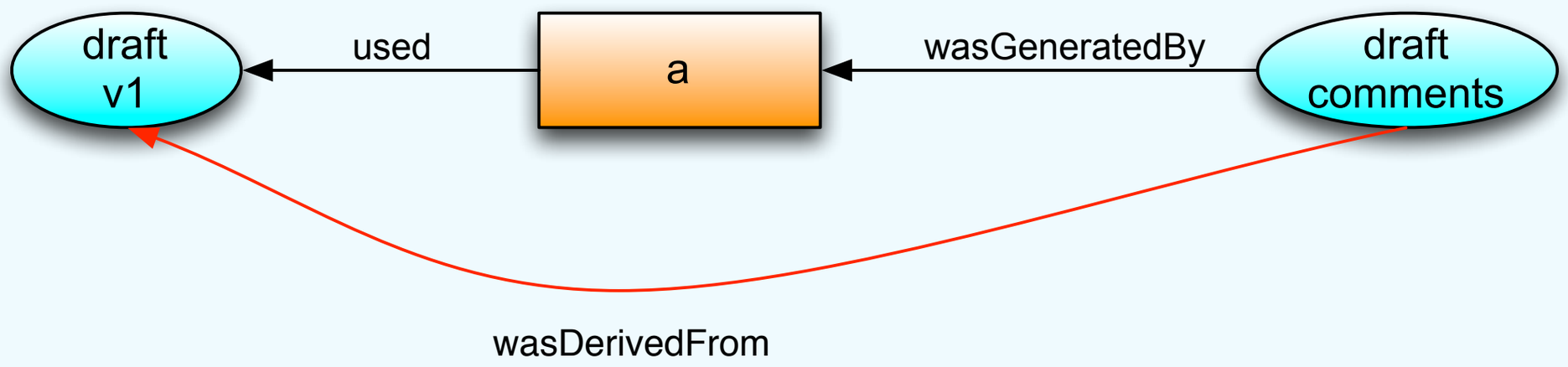
optional references to gen, usage events

```
wasDerivedFrom(id; e2, e1, a, g2, u1, attrs)
```

Derivation, Generation, Usage




```
wasDerivedFrom(draftV1, draftComments, _,_,_)
```




```
wasDerivedFrom(draftV1, draftComments, a, use1, gen1)
```

```
⇒ wasGeneratedBy(gen1; draftComments, a)
```

```
⇒ used(use1; a, draftV1)
```

Derivation, Generation, Usage

Given:

```
wasDerivedFrom(id; e2, e1, a, g2, u1, attrs)
```

where a, g2, u1 are not placeholders ‘-’, we can infer:

```
used(use1; a,e1,_t1,[])
```

and

```
wasGeneratedBy(gen2; e2,a,_t2,[]).
```

for some time stamps _t1, _t2.

If any of the optionals are placeholders, then no inference occurs, i.e.:

```
wasDerivedFrom(id; e2, e1, -, -, -, attrs)
```

PROV-DM relations at a glance

		Object				
		Entity		Activity		Agent
Subject	Entity	**WasDerivedFrom** Revision Quotation PrimarySource AlternateOf SpecializationOf HadMember		**WasGeneratedBy** WasInvalidatedBy	*R* *T* *L*	**WasAttributedTo**
	Activity	**Used** WasStartedBy WasEndedBy	*R* *T* *L*	**WasInformedBy**		**WasAssociatedWith** *R*
	Agent	—		—		**ActedOnBehalfOf**

PROV-DM relations at a glance

		Object				
		Entity		Activity		Agent
Subject	Entity	**WasDerivedFrom** Revision Quotation PrimarySource AlternateOf SpecializationOf HadMember		**WasGeneratedBy** WasInvalidatedBy	*R* *T* *L*	**WasAttributedTo**
	Activity	**Used** WasStartedBy WasEndedBy	*R* *T* *L*	**WasInformedBy**		**WasAssociatedWith** *R*
	Agent	—		—		**ActedOnBehalfOf**

Secondary optional elements in PROV-DM Relations

		Secondary Object		
		Entity	Activity	Agent
Subject	Entity	—	WasDerivedFrom (activity)	—
	Activity	WasAssociatedWith (plan)	WasStartedBy (starter) WasEndedBy (ender)	—
	Agent	—	ActedOnBehalfOf (activity)	—

Ternary relations - plans

Most relation types have two arguments which are { Entity, Activity, Agent}

Derivation is one exception:

```
wasDerivedFrom(id; e2, e1, a, g2, u1, attrs)
```

Two other notable exceptions:

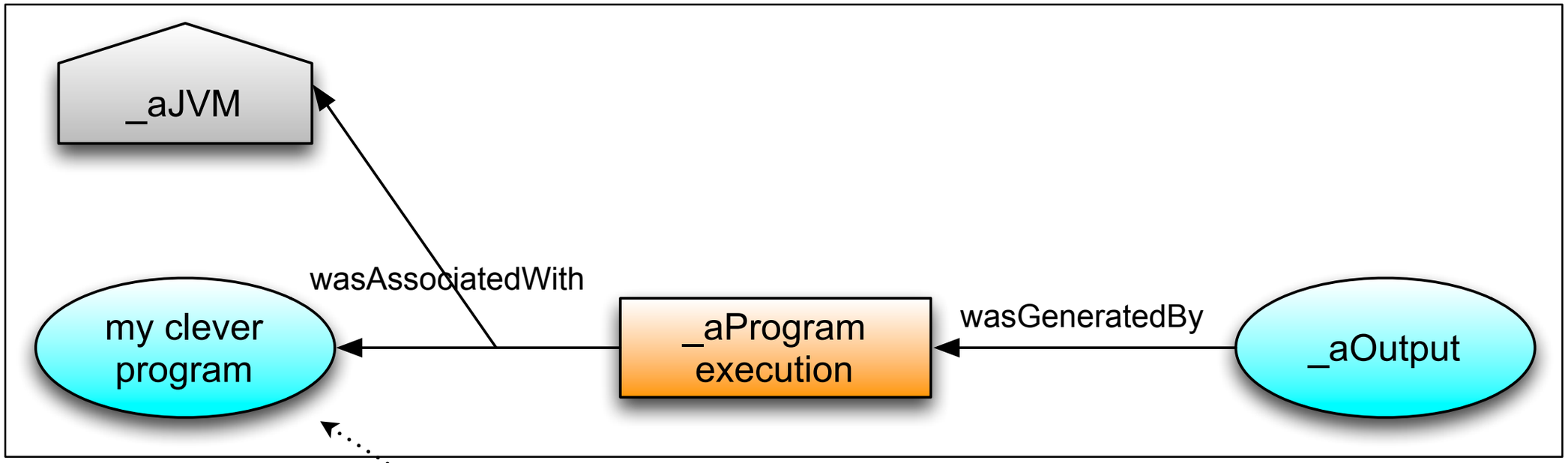
- Associations with a plan

- Delegation with an activity scope

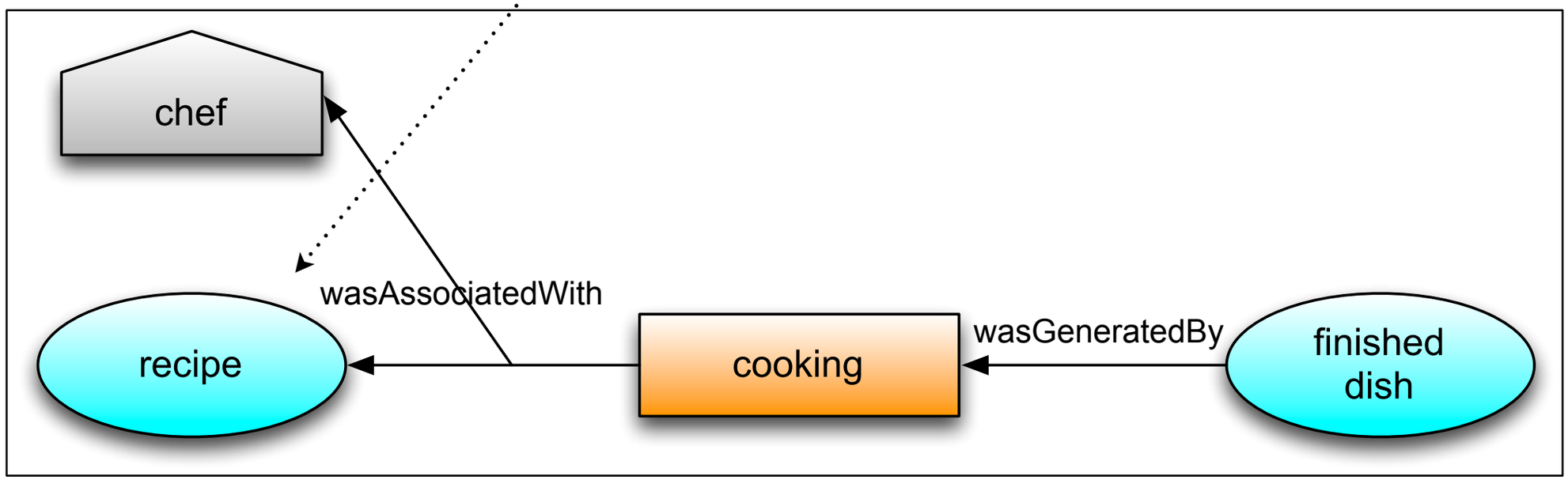
```
wasAssociatedWith(id; a, ag, pl, attrs)
```

A **plan** is an entity that represents a set of actions or steps intended by one or more agents to achieve some goal

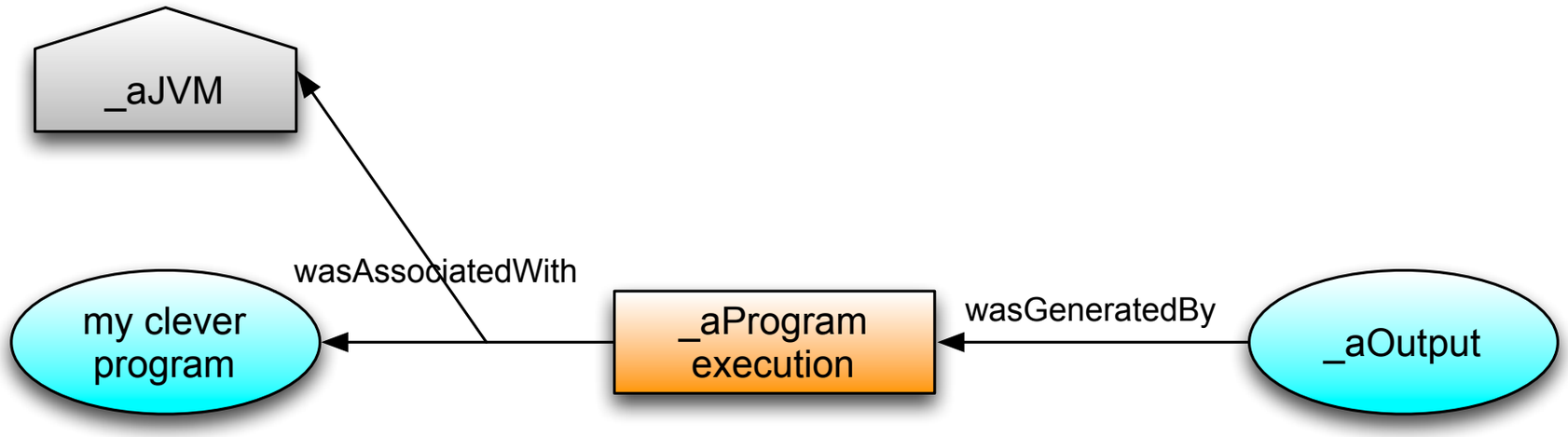
Association with a plan



A **plan** plays a role in an association



Plans are typed entities



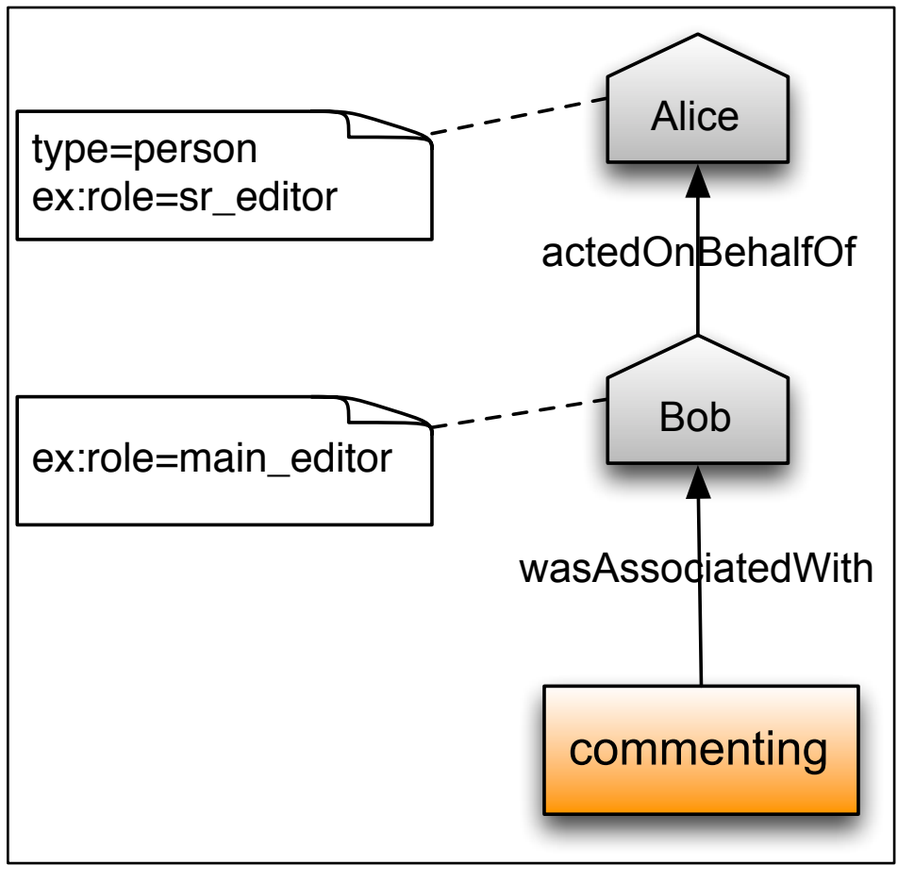
A plan is an entity having **prov:type “prov:plan”**

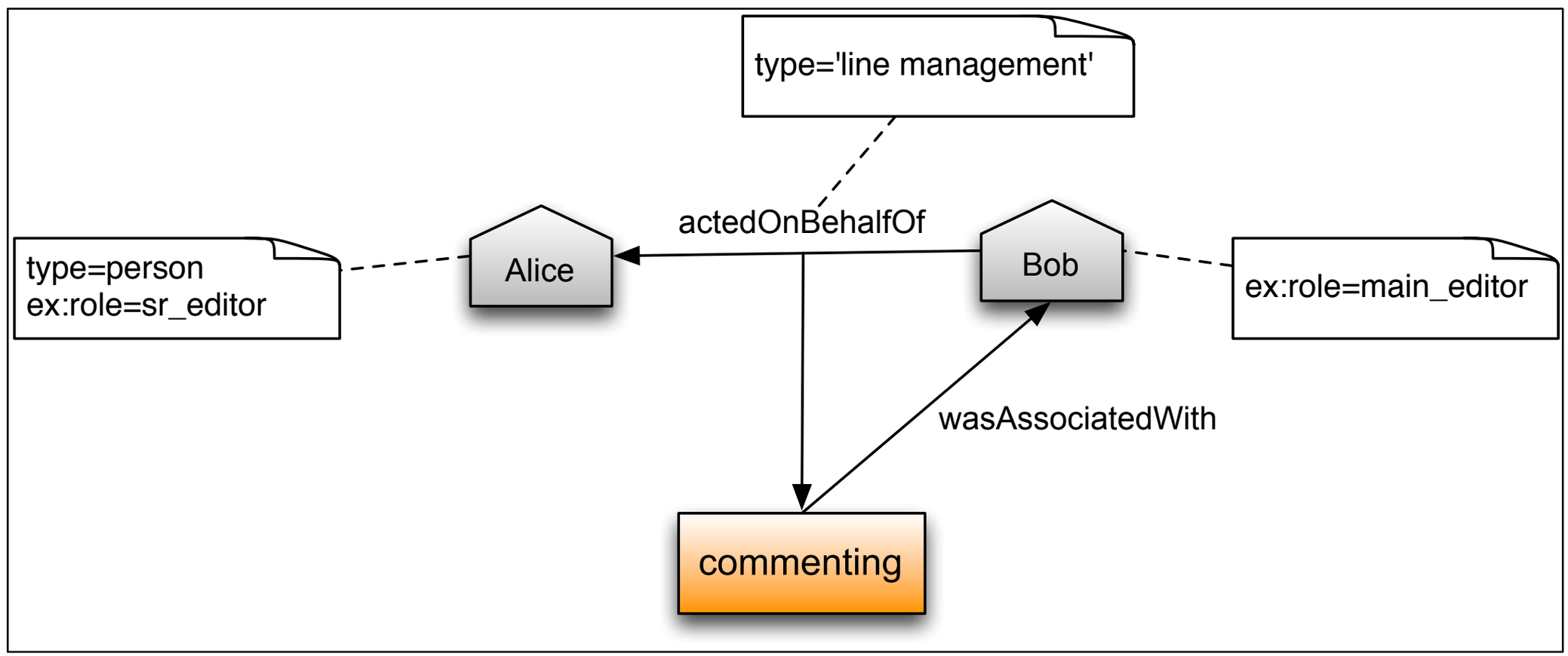
```
activity(ex:_aProgramExecution, [ex:execTime="22.5sec"])
agent(ex:_aJVM, [prov:type = “JVM-6.0”])
entity(ex:myCleverProgram,
        [prov:type='prov:Plan', ex:label="Program 1"])

wasAssociatedWith(ex:_aProgramExecution, ex:_aJVM,
                  ex:myCleverProgram,
                  [prov:role="defaultRuntime",
                   ex:accessPath="webapp" ])
```

Plans are optional.

Constraint 50.13: if a plan argument pl is specified, then pl must be of type Entity

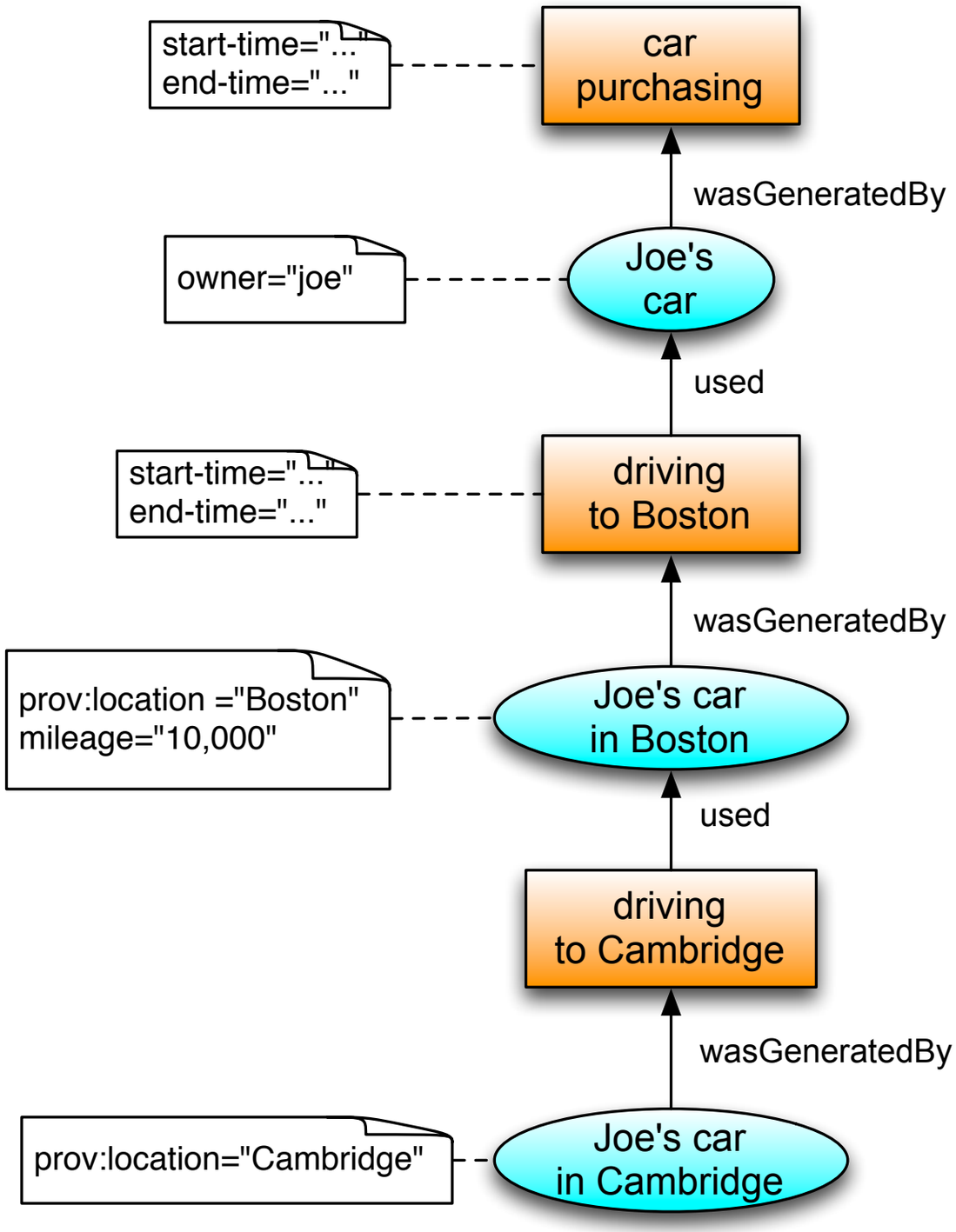
Delegation within an activity scope





Real-world artifacts vs provenance entities

"What do I know about the car I see in this Cambridge street today?"



- It was bought by Joe in 2011
- Joe drove it to Boston on March 16th, 2013. The car has now got 10,000 miles on it
- Joe drove it to Cambridge on March 18th, 2013.

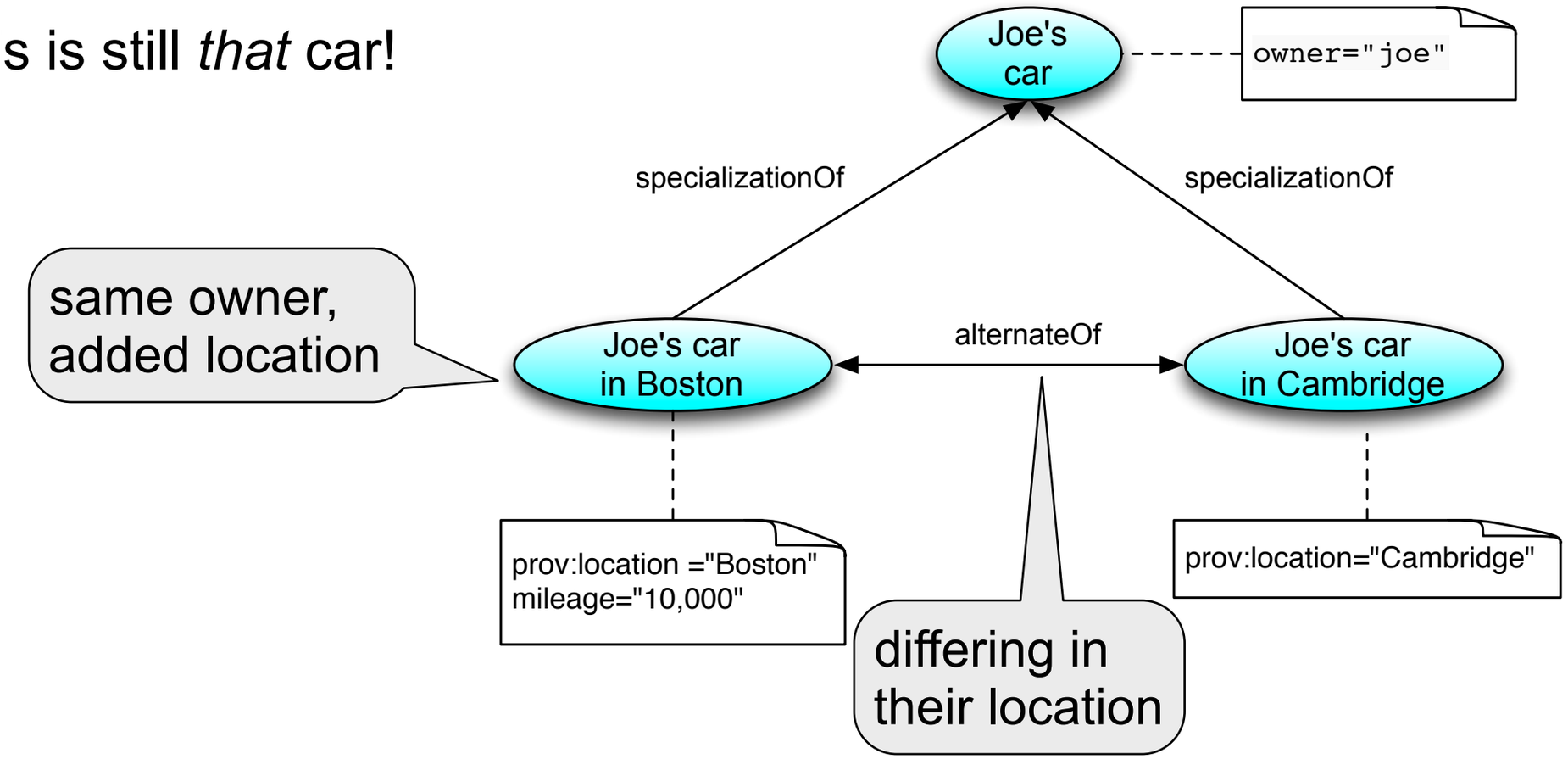
"Same" car, but different provenance at each stage of its evolution

ref: http://www.w3.org/2001/sw/wiki/PROV-FAQ#Examples_of_Provenance

To Core Elements

Alternate-specialization pattern

...But, this is still *that* car!



*An entity that is a **specialization** of another shares all aspects of the latter, and additionally presents more specific aspects of the same thing as the latter.*

*Two **alternate** entities present aspects of the same thing. These aspects may be the same or different, and the alternate entities may or may not overlap in time.*

Semantic notes:

1. Specialization implies alternate: IF specializationOf(e1,e2) THEN alternateOf(e1,e2).

2. Alternate is symmetric: IF alternateOf(e1,e2) THEN alternateOf(e2,e1)

3. Specialization is transitive: IF specializationOf(e1,e2) and specializationOf(e2,e3) THEN specializationOf(e1,e3).

To Core Elements

Reserved attributes and types

A small set of reserved attributes, with some usage restrictions

Attribute	Allowed In
prov:label	*any construct*
prov:location	Entity, Activity, Agent, Usage, Generation, Invalidation, Start, and End
prov:role	Usage, Generation, Invalidation, Association, Start, and End
prov:type	*any construct*
prov:value	Entity

Table 9 ◊: PROV-DM Predefined Types

Type	Specification	Core concept
`prov:Bundle`	Section 5.4.1	Entity
`prov:Collection`	Section 5.6.1	Entity
`prov:EmptyCollection`	Section 5.6.1	Entity
`prov:Organization`	Section 5.3.1	Agent
`prov:Person`	Section 5.3.1	Agent
`prov:Plan`	Section 5.1.1	Entity
`prov:PrimarySource`	Section 5.2.4	Derivation
`prov:Quotation`	Section 5.2.3	Derivation
`prov:Revision`	Section 5.2.2	Derivation
`prov:SoftwareAgent`	Section 5.3.1	Agent

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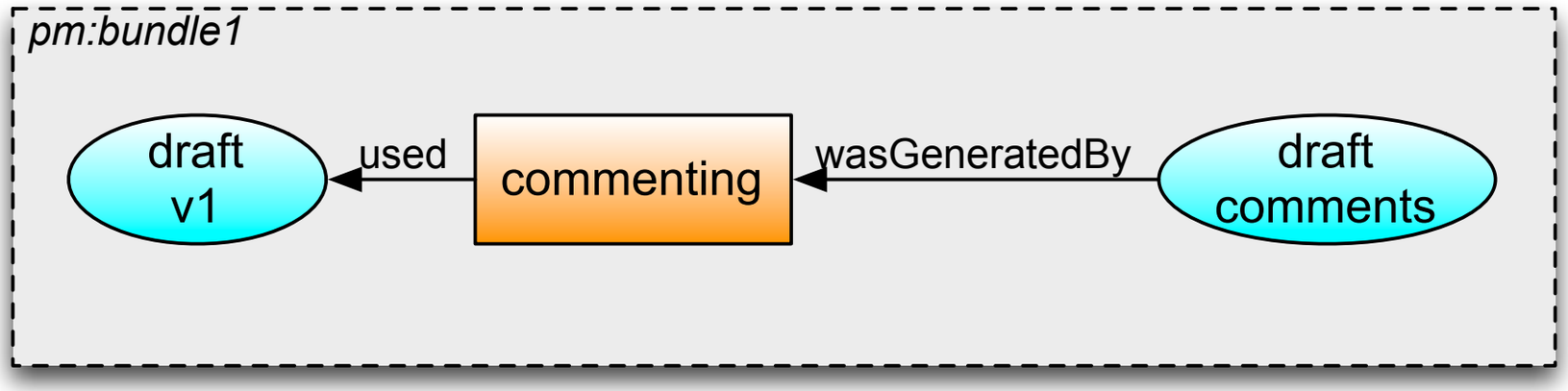
`prov:EmptyCollection`	Section 5.6.1	Entity
`prov:Organization`	Section 5.3.1	Agent
`prov:Person`	Section 5.3.1	Agent
`prov:Plan`	Section 5.1.1	Entity
`prov:PrimarySource`	Section 5.2.4	Derivation
`prov:Quotation`	Section 5.2.3	Derivation
`prov:Revision`	Section 5.2.2	Derivation
`prov:SoftwareAgent`	Section 5.3.1	Agent

Bundles, provenance of provenance

*A **bundle** is a named set of provenance descriptions, and is itself an entity, so allowing provenance of provenance to be expressed.*




```
bundle pm:bundle1

entity(ex:draftComments)
entity(ex:draftV1)

activity(ex:commenting)
wasGeneratedBy(ex:draftComments, ex:commenting,-)
used(ex:commenting, ex:draftV1, -)
endBundle
...
entity(pm:bundle1, [ prov:type='prov:Bundle' ])
wasGeneratedBy(pm:bundle1, -, 2013-03-20T10:30:00)
wasAttributedTo(pm:bundle1, ex:Bob)
```

Time, Events

- Provenance statements are combined by different systems

- An application may not be able to align the times involved to a single global timeline

Therefore, PROV minimizes assumptions about time

> Instead, the PROV data model is implicitly based on a notion of ***instantaneous event***s, that mark transitions in the world (*)

Events:

- activity start, activity end,

- entity generation , entity usage, entity invalidation

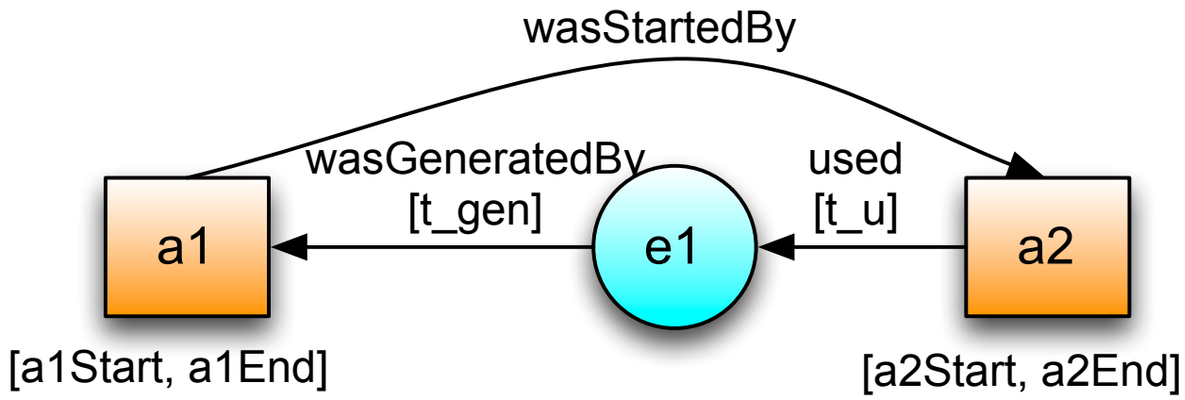
```
wasStartedBy(id; a2, e, a1, t, attrs)
```

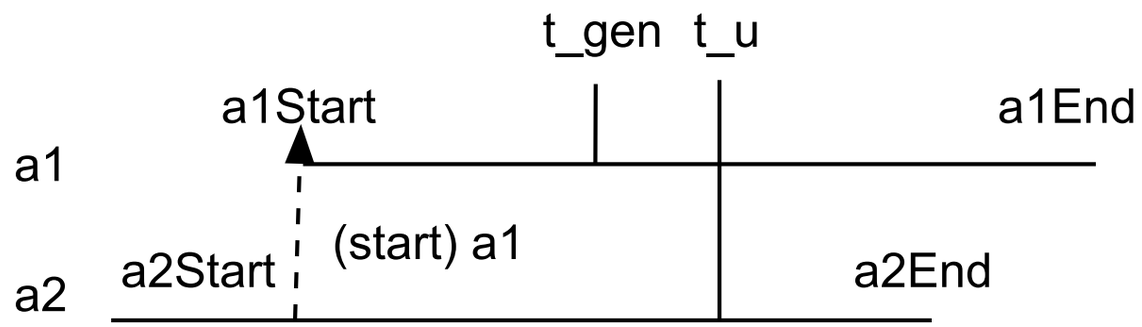
```
wasEndedBy(id; a2, e, a1, t, attrs)
```


(*) PROV-CONSTR http://www.w3.org/TR/prov-constraints/#events (non-normative)

From “scruffy” provenance to “valid” provenance

- Are all possible temporal partial ordering of events equally acceptable?
- How can we specify the set of all valid orderings?





More generally, how do we formally define what it means for a set of provenance statements to be *valid*?

On to part II...