Qualitative Modeling of Spatial Prepositions and Motion Expressions

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Introduction

- Overview of geometric idealizations underlying spatial prepositional phrases.
- Linguistic patterns of motion verbs across languages.
- A qualitative model for static spatial descriptions and for path verbs.
- Overview of relevant annotation schemes.

45 mins

Linguistic Insight (1): Spatial Abstractions

- (1) The ball rolled toward the lamp for 10 seconds. *A geometric **point** (figure) moving towards another **point** (the ground) for a bounded temporal extent*
- (2) The ball rolled across the railway bed. *A **point** moving along a **path** that is a **line***
- (3) The trickle flowed along the ledge. *A **line** moving coaxially along the linear **path*** (Talmy 1983, 2000)
- Speaker abstracts away from irrelevant details such as the length or orientation of the path, representing each spatial scene using a **schema**, and the hearer in turn is able to recreate the scenes from the schema.
- Talmy points out that these representations do not rely on Euclidean geometry and the properties of metric spaces, emphasizing instead topological relations that remain invariant irrespective of changes in sizes, distances, and shapes of the objects.

NL Communication and Qualitative Reasoning

- While understanding spatial descriptions appears to rely on interpreting such topological and geometrical relationships, it does NOT require precise geometries.
  - Humans communicate successfully by and large without specifying the relatively exact (e.g., GPS) positions of objects and their shapes.
- Humans can describe and understand fairly elaborate motions, without needing to drill down into equations that characterize the physical motions signaled by these verbs.
- The use of imprecise and often incomplete qualitative geometric descriptions (instead of quantitative ones such as specifying the coordinates and shapes of every object) allows human communication to be highly efficient.

AI Insight: Qualitative Spatial Reasoning

- Having an artificial agent reason qualitatively allows for reasoning to be more efficient in some situations, since abstracting away from numerical details allows the agent to focus on more compact representations that isolate just the relevant information needed to solve a particular problem.
- AI approaches to qualitative reasoning have a rich set of geometric primitives for representing time, space (including **distance**, **orientation**, and **topological relations** involving notions such as contact and containment), and together with those, motion.
- QSR has been successfully applied to military sketch maps (Forbus et al. 2003), meteorology (Bailey-Kellogg and Zhao 2003), robot navigation (Moratz and Wallgrün 2003), integration of sensor information for environmental monitoring (Jung and Nittel 2008), etc.

Spatial Prepositions and Cognitive Linguistics

- (Johnson 1987, Mandler 2004, Lakoff and Johnson 1980, Evans et al. 2007) Basic topological concepts like **contact** and **inclusion** (in the spatial sense of **enclosure**) are formed through the infant's interaction with objects.
- Schema of the 'container' underlies both the 'enclosure' or 'inclusion' sense of *in* in (4a) and its metaphorical extension in (4b).
  - (4a) The cat is *in* the house.
  - (4b) The cat is *in* trouble.
- Argument by appeal to arbitrary spatial distinctions proliferates senses in unprincipled manner.
- No underlying set of primitives to constrain the representation

(5a) The helicopter hovered *over* the ocean. *Ground is an extended object*

(5b) The hummingbird hovered *over* the flower. *Ground is NOT an extended object* (Lakoff 1987).

(5c) The boy climbed *over* the wall. *Contact with ground object*

(5d) The tennis ball flew *over* the wall. *No contact with ground object*

(5e) Joan nailed a board *over* the hole in the ceiling. *Covering and occlusion of ground object*

(5f) The heavy rains caused the river to flow *over* its banks. *container overflowing, with the figure rising higher than the top of the ground object.* Tyler and Evans (2001)

Cognitive Linguistics with Primitives

- Jackendoff (1983, 1990): Theory of Lexical Conceptual Structure (LCS) introduces primitives such as IN, ON, TOWARDS, INSIDE, VIA, etc.
  - (6) [John ran] *toward* the house.
    [Path TOWARD ([Thing house])]
  - (7) [The car passed] *through* the tunnel.
    [Path VIA ([Place INSIDE ([Thing tunnel)])]
- While the semantics of LCS is obviously compositional, it is not intended to be truth-conditional (although can be cast as such, cf. (Zwarts and Verkuyl 1994))
- Since it has no basis in logic, Conceptual Structure cannot be used to make logical inferences, and as such cannot account for entailments between sentences.
- Primitives are not further elaborated to support reasoning; they are functors in a compositional syntax, but are not differentiated from each other in terms of semantics.
- Geometry used is far too abstract to be relevant to computational modeling of spatial relations.

Linguistic Insight (2): Frames of Reference

- Substantial differences across languages in the way one can specify a ‘figure’ object as being in a particular **orientation** (“left”, “east”, “under”, etc.) with respect to another reference or ‘ground’ object and possibly a third object, the viewer.
- Studies of speakers across a wide variety of languages have revealed a basic inventory of three types of geometric coordinate systems (**frames of reference**) whose types are unevenly distributed, along with a variety of idiosyncratic instantiations, across languages (Levinson 2003).
- The human ability to refer to and pick out objects in space relies on these particular frames of reference.

Linguistic Spatiotemporal Reasoning

- Study how space is conceptualized through language;
- Create a computational semantics of temporal and spatial expressions in language;
- Model the mapping of spatial and motion language to qualitative representations;
  Build a dynamic model of motion expressions;
- Use these models to express linguistic information about space and motion as "sketches" or grounded representations.

Issues in Motion Identification

- Sentences usually involve more than one individual in motion.
- The man chased the car down the street, dodging on-coming cars and pedestrians crossing at the intersection.
- Locations of individuals are often implicit.
- The man left. The hurricane is near.
- Not all mentions of motion are successful.
- Mary left for Washington, but missed her flight. They send a probe to Mars, but it never got there.
- Motion predicates don't always refer to motion.
- He walked us through the museum / the budget cuts. The runner ran fast. The meeting ran smoothly.

Expressing Movement in Language

- Guatemala, April 21, 2007
- David left San Cristobal de Las Casas four days ago.
- David arrived in Ocosingo that day.
- The next day, David biked to Agua Azul and played in the waterfalls there for 4 hours.
- David spent the next day at the ruins of Palenque.
  The following day, David drove to the border with Guatemala.

Motion scales and change

- Language encodes motion in Path and Manner constructions
- Path: change with distinguished location
- Manner: motion with no distinguished locations
- Manner and paths may compose.

Modes of Spatial Information

- Static Spatial Relations
  - PP; Mary is on/in the chair.
  - Verbal; The tree stands in the middle of the yard.
- Dynamic Spatial Relations
  - PP; Mary walked to the room.
  - Verbal; The tree fell down.
- Polysemy of Spatial Prepositions
  - over; over the bridge, over the hill.
  - at, on; on the table/wall/ceiling, at the computer/party.
  - in; in the coffee, in the cup, in the bowl.

Types of Spatial Expressions

- Constructions that make explicit reference to the spatial attributes of an object or spatial relations between objects
- Four grammatically defined classes:
  - Spatial Prepositions and Particles: *on, in, under, over, up, down, left of*
  - Verbs of Position and Movement: *lean over, sit, run, swim, arrive*
  - Spatial Attributes: *tall, long, wide, deep*
  - Spatial Nominals: *area, room, center, corner, front, hallway*

II: Calculi for Qualitative Spatial Reasoning

40 mins

Overview

- Semantics of spatial prepositional phrases mapped to qualitative spatial reasoning.
- Qualitative calculi for representing topological and orientation relations.
- Qualitative calculi for representing motion.

Prepositions: Traditional Classification

- Directional
  - involve a path and/or movement
  - *across, around, from, into, onto, and to*.
- Locative preps
  - projective: involve a point-of-view
    - *above, behind, below, beside, in front of, over, under*
  - non-projective
    - *at, between, in, inside, on, outside, near*

Revised Classification

- Prepositions have up to three aspects of meaning
  - Topology
  - Orientation
  - Function
- One or more of these aspects may be present in any given usage context

Topology

- Analysis of properties of objects that remain invariant across deformations due to changes in length and angle.
  - a circle can be stretched into an ellipse
  - a cup can be absorbed into the donut begun by its handle.
- Focus in linguistics: coincidence, contact, containment.
- Prepositions with topological meaning:
  - *above, around, at, in, inside, on, over*

in

Miller and Johnson-Laird (1976), Herskovits (1986), Talmy (1983, 2000), Cohn et al. (1997), Zwarts and Winter (2000)

- figure object can be enclosed by ground object *a city in Sweden*
- ground object can be a container, with figure above its bottom *the coffee in the cup*
- figure can have a part that is totally inside ground object, and above its bottom *the spoon in the cup*
- figure has a part that touches ground object *the bulb in the socket*
- ground object must be in its canonical vertical orientation, and part of figure is outside ground object *the pears in the bowl*
- figure can be inside convex hull of ground object *the bird in the tree*
- etc.

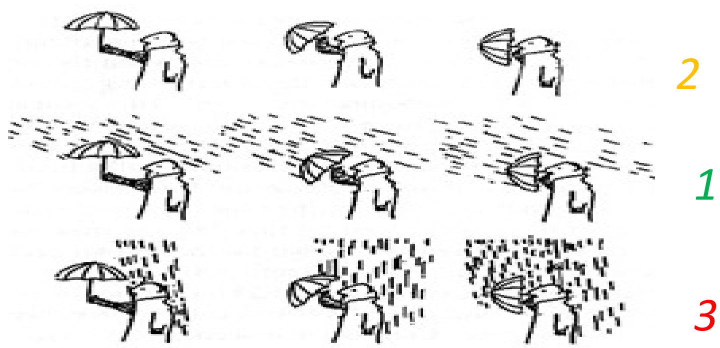
on

- figure can be in contact with ground object *the picture on the wall*
- ground object can support figure, which is above it, but may or may not be in contact with figure *the lamp on the table*
  - figure can be part of region of interaction with ground object
- figure is the front part of the ground object *the wrinkles on his forehead*
- figure can be on boundary of ground object *the house on the river*
- figure can be on top surface of ground object *the boat on the river*

over

Coventry et al. (2001), Tyler and Evans (2001), Herskovits (1986), Talmy (1983, 2000)

- figure can be in contact with ground object *the boy climbed over the wall.*
- figure can be above ground object, though exact orientation depends on figure's function *the tennis ball flew over the net; the helicopter hovered over the ocean.*
- figure can occlude ground object *Joan nailed a board over the hole in the ceiling.*

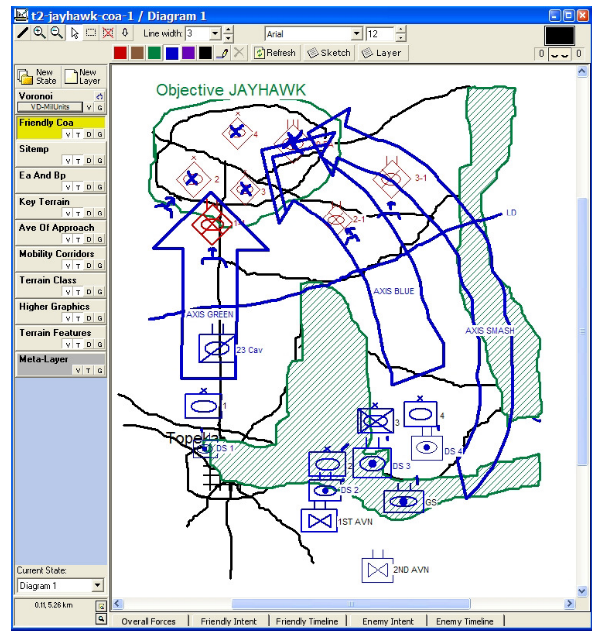


Acceptability ratings for
The umbrella is over the man

Mapping from Language to Qualitative Spatial Representations

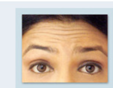
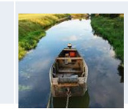
- Qualitative Reasoning allows agents to reason about behavior of the world, without precise quantitative information as found in numerical simulation
- Qualitative Spatial Reasoning has been applied to military sketch maps, meteorology, GIS querying, route planning, etc.
- Domain objects
  - Points (0D)
  - Sets of points
  - Lines (1D)
  - Regions (2D or 3D)
- Properties of these objects
  - Convexity
  - Concavity
  - Other shape constraints
- Basic Relations
  - Topology
  - Orientation
  - Metric

Pix from Forbus et al. (2003)



Topological Relations

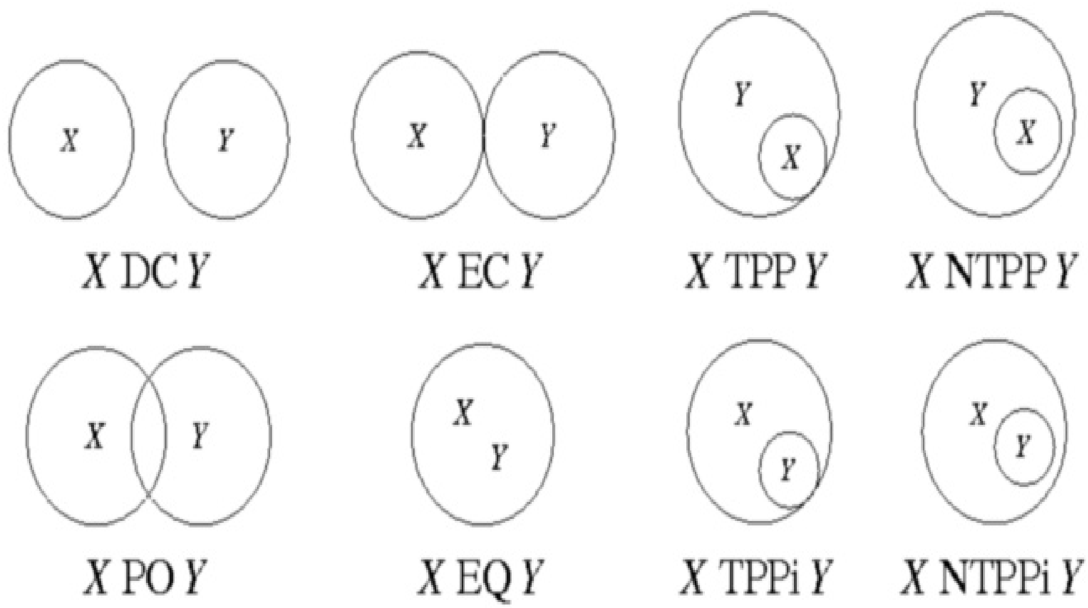
- Topology: Analysis of properties of objects that remain invariant across deformations due to changes in length and angle.
  - a circle can be stretched into an ellipse
  - a cup can be absorbed into the donut begun by its handle.
- Focus in linguistics: qualitative relations of coincidence, contact, containment.
- Prepositions expressing topological relations:
  - ***above, around, at, in, inside, on, over***

Figure object can be enclosed by ground object	***a city in Sweden***	
Figure can have a part that is outside ground object, and figure is above bottom of ground object	***the spoon in the cup***	
Figure is the front part of the ground object	***the wrinkles on her forehead***	
Figure can be on boundary of ground object	***the house on the river***	
Figure can be on top surface of ground object	***the boat on the river***	

RCC-8 Calculus

Cohn et al. (1997)

- Treat entities as (primitive) regions that are non-empty, finite, and of the same dimension (and not of mixed dimension)
- Regions can consist of multiple pieces
- 8 basic relations among regions, based on a single primitive called **Connect(x, y)**
- 2^8 = 256 combinations

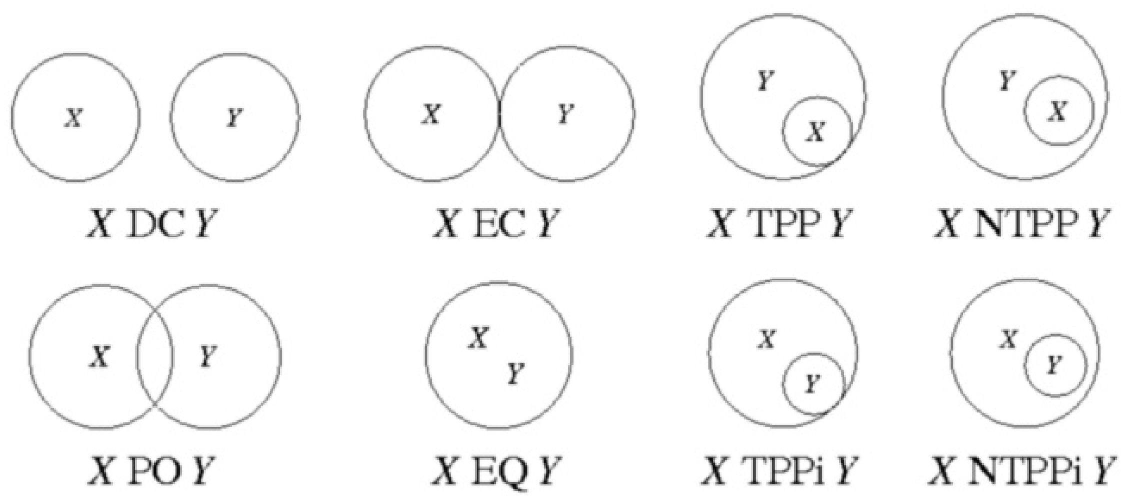


(Randell, Cui and Cohn, 1992)

RCC-8 Meretopology

1. $\text{DC}(x, y) \overset{\text{def}}{=} \sim \text{Connect}(x, y)$.
2. $\text{Part}(x, y) \overset{\text{def}}{=} \forall z\ \text{Connect}(z, x) \rightarrow \text{Connect}(z, y)$.
3. $\text{EQ}(x, y) \overset{\text{def}}{=} \text{Part}(x, y) \wedge \text{Part}(y, x)$.
4. $\text{Overlap}(x, y) \overset{\text{def}}{=} \exists z\ \text{Part}(z, x) \wedge \text{Part}(z, y)$.
5. $\text{EC}(x, y) \overset{\text{def}}{=} \text{Connect}(x, y) \wedge \sim \text{Overlap}(x, y)$.
6. $\text{PO}(x, y) \overset{\text{def}}{=} \text{Overlap}(x, y) \wedge \sim \text{Part}(x, y) \wedge \sim \text{Part}(y, x)$.
7. $\text{PP}(x, y) \overset{\text{def}}{=} \text{Part}(x, y) \wedge \text{not Part}(y, x)$.
8. $\text{TPP}(x, y) \overset{\text{def}}{=} \text{PP}(x, y) \wedge \exists z[\text{EC}(z, x) \wedge \text{EC}(z, y)]$
9. $\text{NTPP}(x, y) \overset{\text{def}}{=} \text{PP}(x, y) \wedge \sim \exists z[\text{EC}(z, x) \wedge \text{EC}(z, y)]$.

Disconnected (DC): A and B do not touch each other.
Externally Connected (EC): A and B touch each other at their boundaries.
Partial Overlap (PO): A and B overlap each other in Euclidean space.
Equal (EQ): A and B occupy the exact same Euclidean space.
Tangential Proper Part (TPP): A is inside B and touches the boundary of B.
Non-tangential Proper Part (NTPP): A is inside B and does not touch the boundary of B.

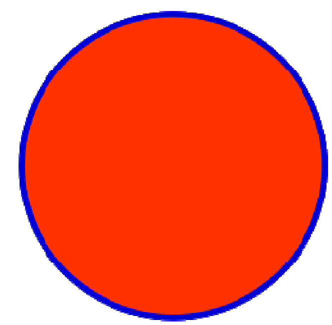


Topological Meaning in RCC-8

a city <u>in</u> Sweden	$TPP(x, y) \lor NTPP(x, y)$
the coffee <u>in</u> the cup	$TPP(x, y)$
the spoon <u>in</u> the cup	$TPP(x', x) \land TPP(x', y)$
the bulb <u>in</u> the socket	$TPP(x', x) \land EC(x', y)$
the lamp <u>on</u> the table	$EC(x, y) \lor (EC(x, z) \land EC(z, y))$
the wrinkles <u>on</u> his forehead	$TPP(x, y)$
the house <u>on</u> the river	$EC(x, y)$
the boat <u>on</u> the river	$NTPP(x, y)$
the boy jumped <u>over</u> the wall	$DC(x, y)$
Joan nailed a board <u>over</u> the hole in the ceiling	$EC(x, y)$
he walked <u>around</u> the pool	$DC(x, y)$
he swam <u>around</u> the pool	$TPP(x, y)$

Beyond RCC-8: Distinguishing Open & Closed Sets

- A **topology on a set** S is a collection of subsets of S containing S, the empty set, and closed under union and finite intersections.
- A **distance metric** on a set of points S is a function d: S x S → $\Re$ with two properties:
  - (i) for any points x, y in S, d(x, y) = 0 iff x = y
  - (ii) d(x, z) ≤ d(x, y) + d(z, y).
- A distance metric d on a set S induces a topology on S called the **metric topology** <S, d> on S defined by d.
- In a metric topology <S, d>, a subset P of S is called an **open set** if for every point x in P, there exists a real number r > 0 such that, given any point y in P with d(x, y) < r, y also belongs to P.
  - Intuitively, an open set is surrounded by other points and does not include its boundary; it thus consists only of **interior points**.
  - A **closed set** includes the points on its boundary.



Boundaries & Connectedness

- *Interior* of X, X^o : union of all open sets contained in X
- *Complement* of X, X': all points not in X
- *Exterior* of X, X^- : $(X')^o$, i.e., union of δX and X'.
- *Closure* of X: intersection of all closed sets containing X; i.e., smallest closed set containing X
  – closure of X is the union of X and δX.
- *Boundary* of X, δX: closure of X $\cap$ closure of X^-
- Two sets X and Y are <u>connected</u> if there is some point in common between their closures.

Egenhofer (1991)

9-Intersection Calculus (9IC)

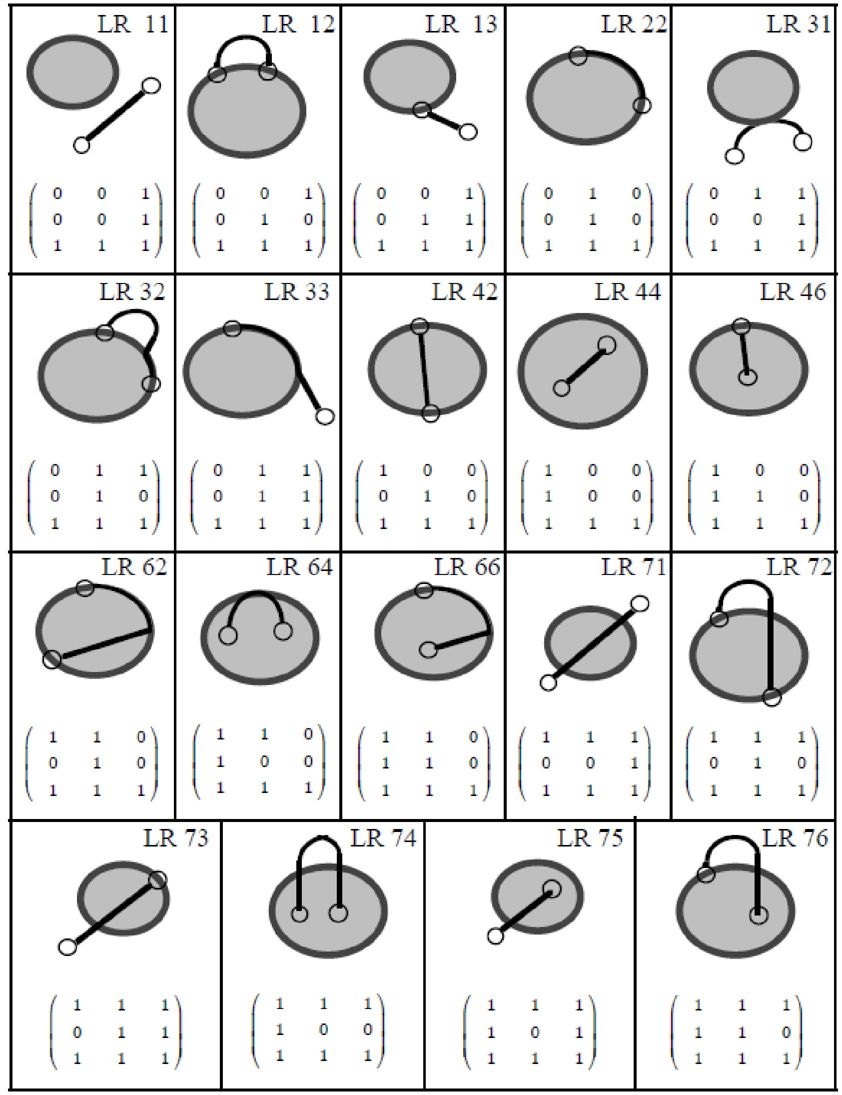
- Consider 2D, one-piece regions without holes
- 9 basic relations between two regions
- $2^9 = 512$ combinations

$A^\circ \cap B^\circ$	$A^\circ \cap \delta B$	$A^\circ \cap B^-$
$\delta A \cap B^\circ$	$\delta A \cap \delta B$	$\delta A \cap B^-$
$A^- \cap B^\circ$	$A^- \cap \delta B$	$A^- \cap B^-$

Egenhofer (1991)

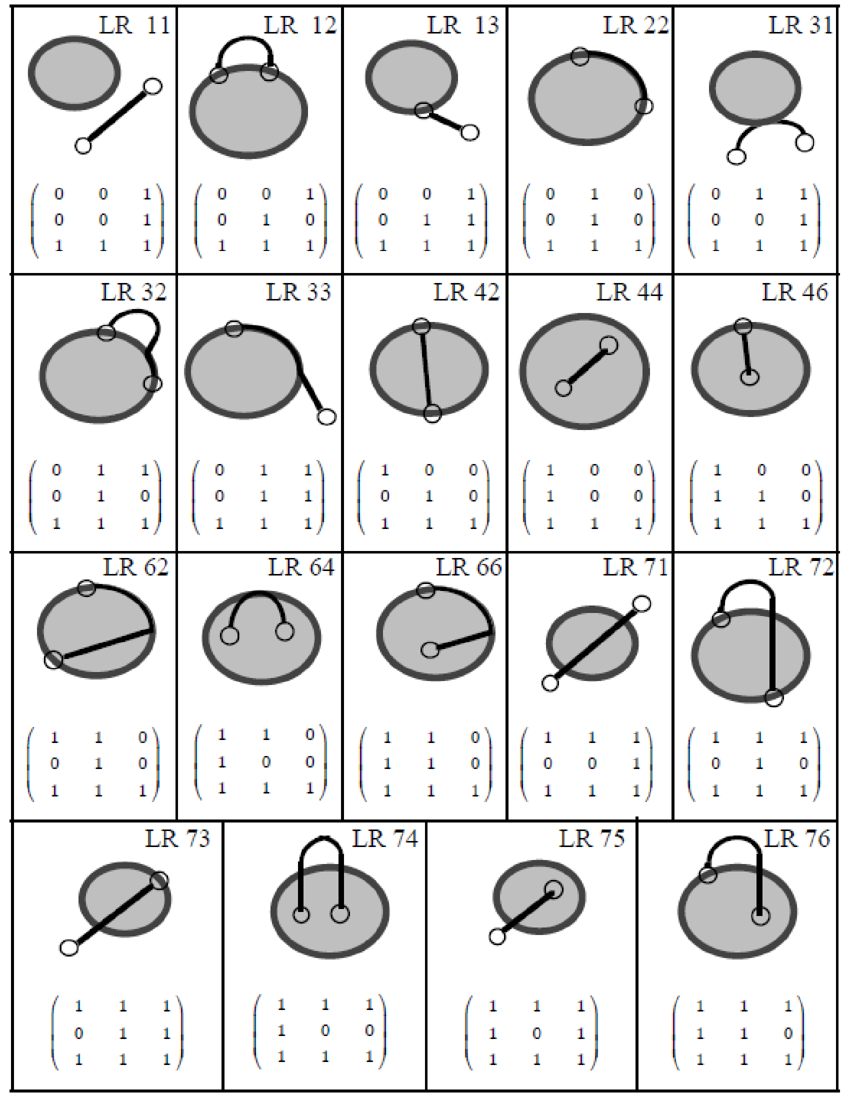
9IC with lines & regions

- Distinguish the interior A^{o}, boundary δA, and exterior A^{-} of a region A (2D, simply-connected region without holes)
- Likewise for a line B (non-branching, non-looping)
- 9 possible intersections of a line's interior, boundary and exterior with that of a region
- 19 possible line-region relations, represent various kinds of inside and outside



NL & 9IC

- *the spoon in the cup* = LR46 or LR73
- 34 subjects were given 64 natural language descriptions of spatial relations (goes across, comes through, etc.) between a road and a park and asked to draw them (Rashid et al. 1998).
  - 6 of the 19 line-region relations showed up frequently.
    - LR 11, LR 13, LR 44, LR 46, LR 71, LR 75
- In a separate task, subjects were presented with a natural language sentence describing a relation between a road and a park, and asked to compare it against each of 60 diagrams, rating their agreement on a five-point scale.
  - The spatial terms that showed the highest agreement involved goes through, enters, goes along, inside, and outside



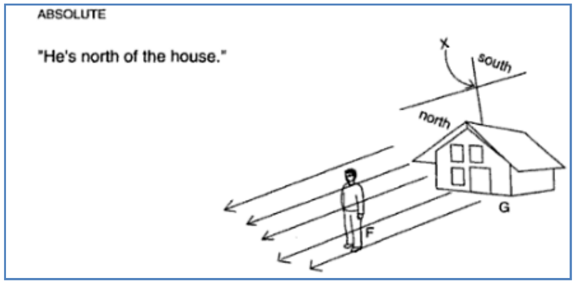
Orientation

- Three different types of coordinate systems (frames of reference) that underlie linguistic descriptions across languages: **absolute**, **intrinsic**, and **relative**
- They involve spatial relations between a figure object (F) and a ground object (G), with F possibly being a part of G.
- Extensive cross-cultural comparison and psychological experiments in Levinson (2003): *Space in Language and Cognition*, based on a decade of work at the Max Planck Institute for Psycholinguistics at Nijmegen.
- Prepositions with orientation meaning:
  - *above, around, over, to the left, north, in front of*

Distribution of Frames of Reference Across Languages

- Intrinsic only: Mopan (Mayan)
- Absolute only: GY
- Relative Only: N.A.
- Intrinsic and Relative: Dutch, Japanese
- Intrinsic and Absolute: Tzeltal, Hai//Om (Khoisan language spoken in Namibia)
- All three: Yucatec (Mayan), Kgalagadi (Bantu)

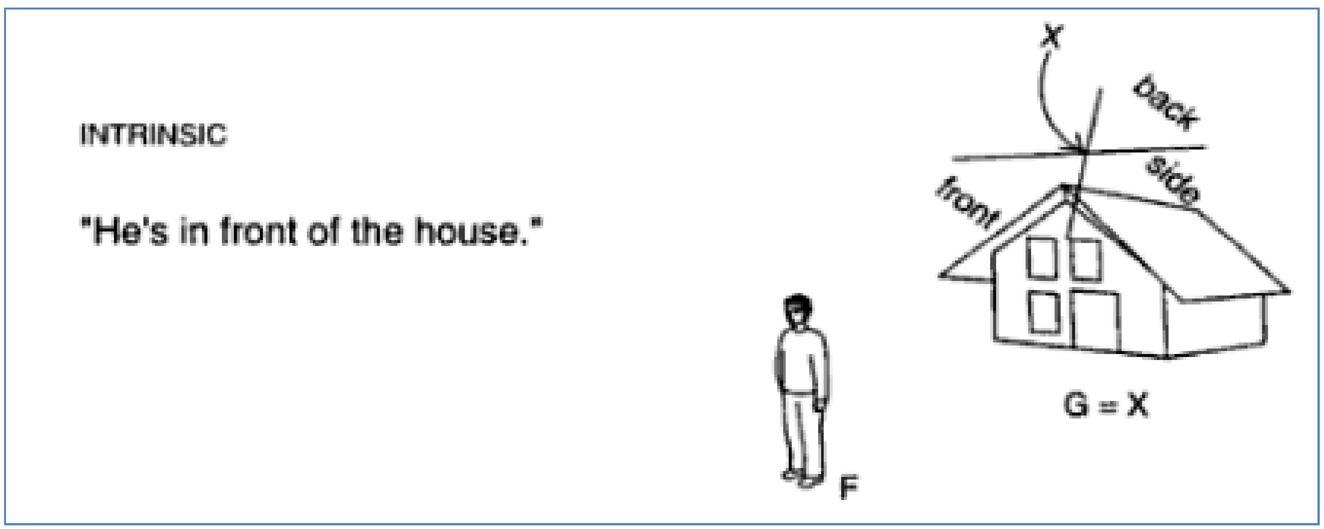
Absolute Frame



- Coordinate system that is anchored to fixed bearings, whose origin is on G.
- R(F, G): F can be found in a search domain at a fixed bearing R from G.
- Cardinal directions need not be expressed in terms of compass points (e.g., *north/south/east/west*), and may use landscape markers, e.g., *uphill/downhill*, *upstream/downstream*, *towards the mountain/towards the sea*, etc.
- Examples
  - *The ant is just north of my foot*, in the Australian language Guugu Yimithirr (GY)
  - *The bottle is uphill of the chair*, in the Mayan language Tzeltal, spoken in Chiapas
- Levinson et al. have argued, based on field experiments, that languages which make extensive use of absolute systems require a remarkable capability for calculating one's bearings with respect to cardinal directions at any point.
- Further, their experiments suggest that the absolute frame tends to influence (or at least interact with) reasoning in specific tasks.

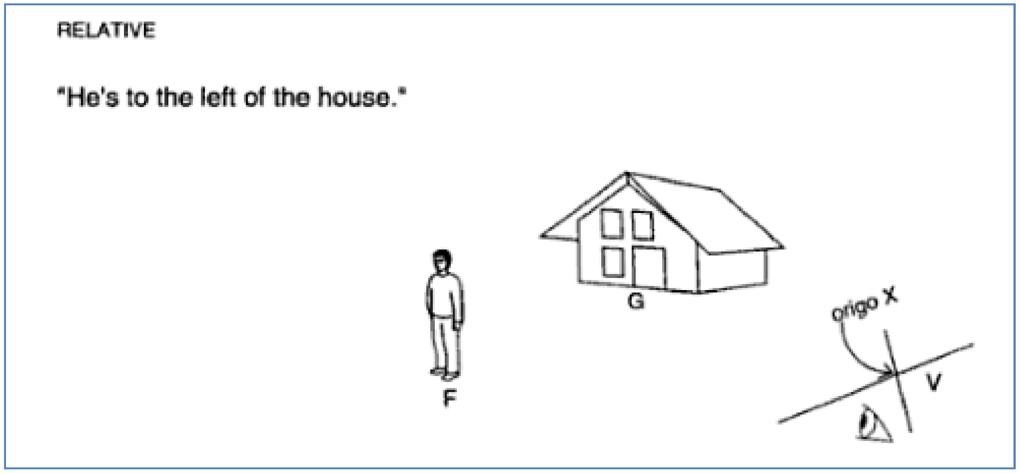
Intrinsic Frame

- Here coordinates are provided by particular facets of G, e.g., “front”, “nose”, “sides”, etc.
- R(F, G) asserts that F lies in a search domain extending from G on the basis of an angle or line projected from center of G, through an anchor point A (usually the named facet R).
- F and G can include oneself (‘ego’).
- Found in most languages, with a few exceptions like GY, which has only an absolute frame of reference.



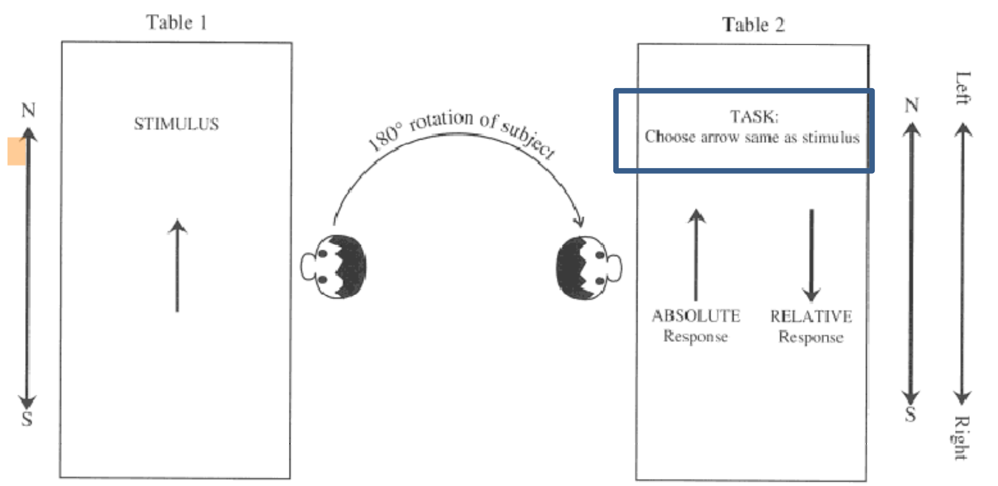
Relative Frame

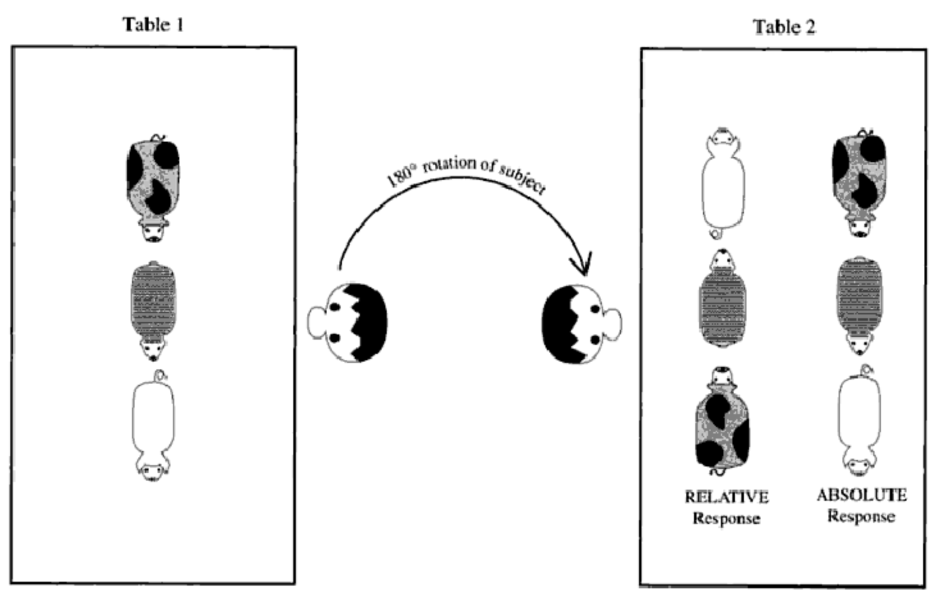
- Involves a ternary relation, R(F, G, V) between F, G, and viewer V.
- There is one coordinate system centered on V, and possibly another, centered on G. When there are two coordinate systems, there is a geometric projection from V's coordinate system to G's. This projection is pseudo-intrinsic, a way of providing intrinsic facets to G by using V.
  - Thus, a tree in English may lack an intrinsic "front", but using the viewer-centered coordinate system, when it has an intrinsic front (especially when the viewer is human), allows the tree to acquire a front.
  - However, in Chamus, an Eastern-Nilotic language spoken in Kenya, trees do have intrinsic fronts (based on direction of lean)!



pix from
Levinson (2003)

Experimental Paradigms (1)



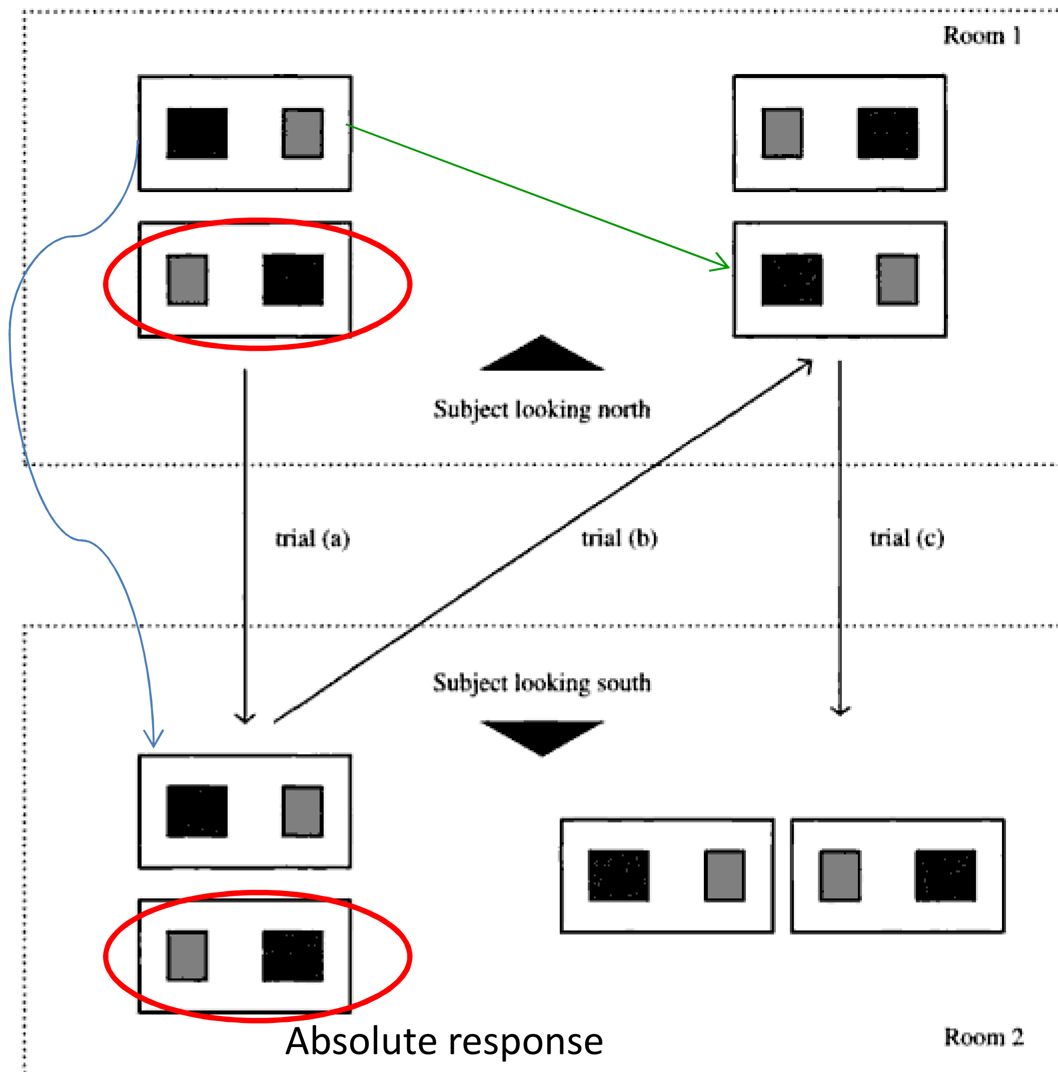


Levinson (2003)

Experimental Paradigms (2)

choose a card

then find matching card



Levinson (2003)

The Linguistic Relativity Claim

GY Speakers

Table 4.3. *Memorizing chips: individual decisions*

		Orientation		
		Absolute	Relative	Total
Group	Hopevale	27	7	34
	Dutch	1	44	45

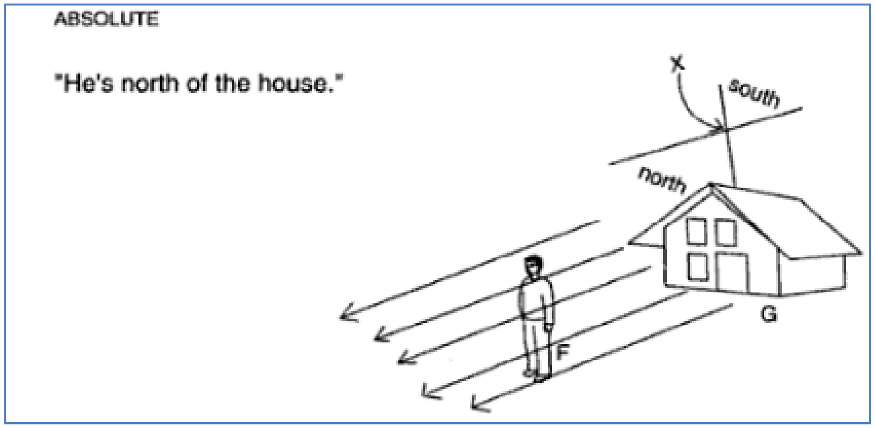
Hopevale vs. chance: p = 0.0004 (Binomial test, P = 0.5 for Absolute, Relative)
Dutch vs. chance: p = 0.0000 (Binomial test, same assumptions)
Hopevale vs. Dutch: p = 0.0000 (Fischer's exact test)

Table 4.4. *Memorizing chips: subjects by majority of choices*

		Orientation		
		Absolute	Relative	Total
Group	Hopevale	9	1	10
	Dutch	0	15	15

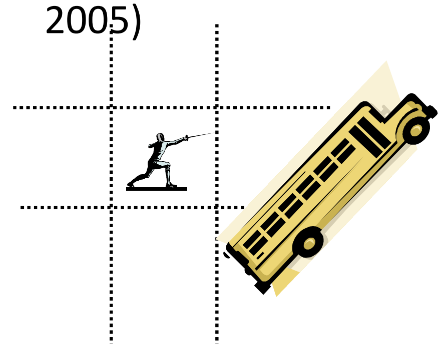
Hopevale vs. chance: p = 0.0107 (Binomial test, P = 0.5 for Absolute, Relative)
Dutch vs. chance: p = 0.0000 (Binomial test, same assumptions)
Hopevale vs. Dutch: p = 0.0000 (Fischer's exact test)

Absolute Frame & Spatial Reasoning



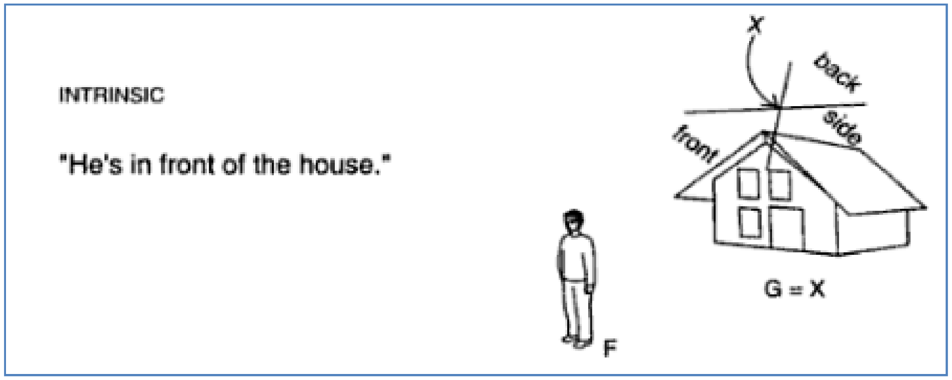
- Coordinate system that is anchored to fixed bearings, whose origin is on G.
- R(F, G): F can be found in a search domain at a fixed bearing R from G.
- Cardinal directions need not be expressed in terms of compass points (e.g., ***north/south/east/west***), and may use landscape markers, e.g., ***uphill/downhill, upstream/downstream, towards the mountain/towards the sea***, etc.

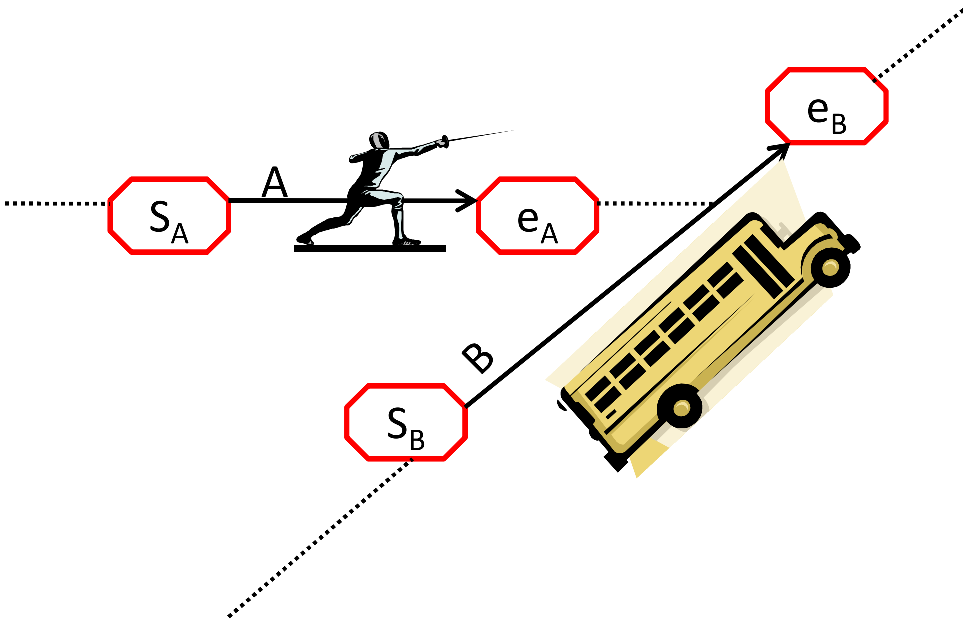
Cardinal Direction Calculus
(Goyal and Egenhofer 2000)
(Skiadopoulos and Koubarakis 2005)



• MBR of ground region is made the central tile of a 9-element grid.
• The figure region is then positioned on the grid, and the tiles it falls into are used to describe its orientation with respect to that central tile (the ground).
• The nine regions are B (ground), S, SW, W, NW, N, NE, E, and SE.
• Here the bus (as a **region**) is partly S, partly E, and partly NE of the person (as a **region**), expressed as *bus NE:E:SE person*.

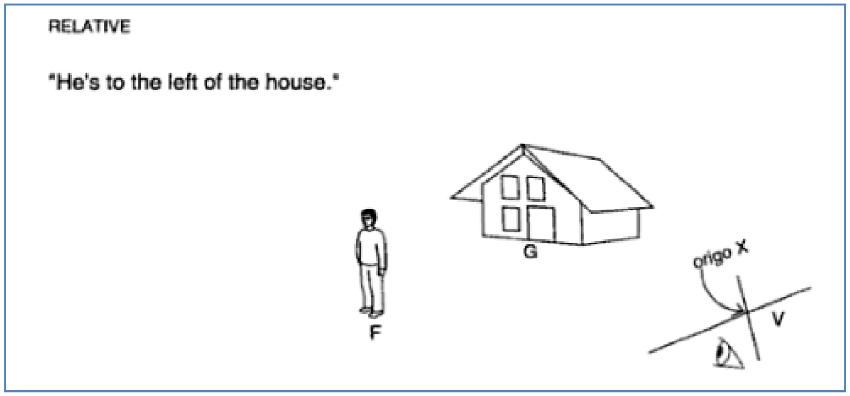
Intrinsic Frame & Spatial Reasoning



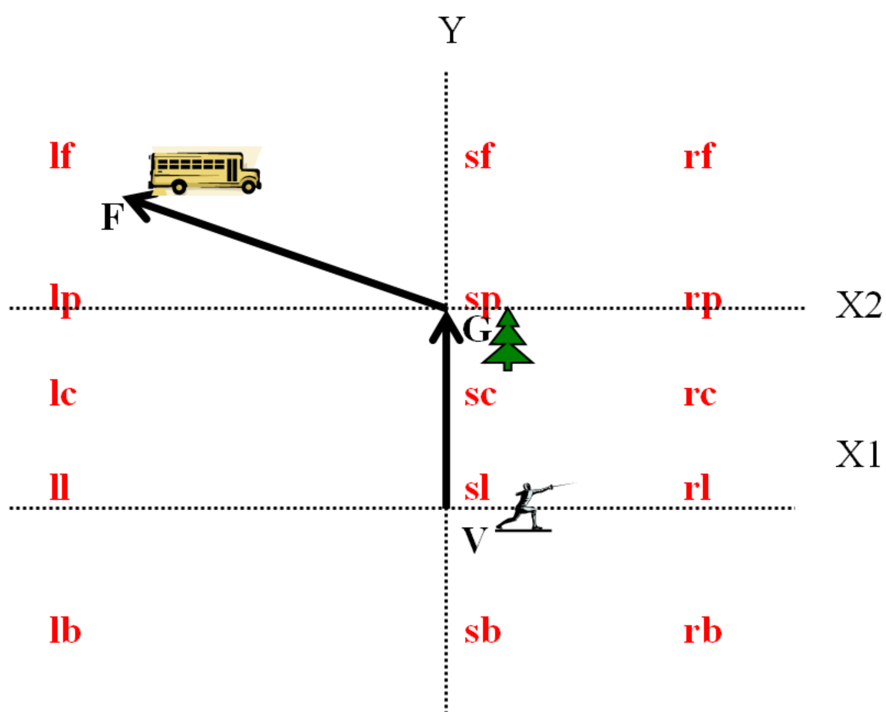


- **Dipole Calculus** Dylla and Moratz (2004)
- A pair of **dipoles** (oriented line segments) in an orientation *rlll*:
  - s_B is ***to the right of*** A (i.e., belongs to the right half-plane of A)
  - e_B is ***to the left*** *of* A
  - s_A is ***to the left of*** B (i.e., belongs to the left half-plane of B)
  - e_A **is *to the left of*** B
- Adding behind, interior, and front to each dipole (DC_{69})
  - *{rlll. rrll}* = {the bus is to the person's **right**, the bus is **in front of** the person}
  - *{sfsi, iebe} = the* ***front*** *of the bus*

Relative Frame & Spatial Reasoning



- Involves a ternary relation, R(F, G, V) between F, G, and viewer V.
- **Double Cross Calculus** (Freksa 1992, Scivos and Nebel 2001) describes the position of a **point** F (e.g., a bus) relative to a line drawn from **point** G (a tree) to viewer at **point** V.



1. The bus is **to the left of** the tree	{lp, lc, ll}
2. The bus is **in front of** the tree 3. The bus is **between me and** the tree	{lc, sc, rc, ll, sl, rl}
4. The bus is **behind** the tree	{lf, sf, rf}
5. The bus is **behind** the viewer	{lb, sb, rb}
6. The bus is **directly in front of** me	{sl, sc, sp}
7. The bus is **at the far left behind** the tree	lf

Topological & Orientation Meaning

a city <u>in</u> Sweden TPP(x, y) ∨ NTPP(x, y)

the coffee <u>in</u> the cupTPP(x, y)

the spoon <u>in</u> the cup TPP(x', x) ∧ TPP(x', y) ∧ iebe(x', x)

the bulb <u>in</u> the socket TPP(x', x) ∧ EC(x', y)

the lamp <u>on</u> the table (EC(x, y) ∨ (EC(x, z) ∧ EC(z, y))) ∧ rlll(x, y)

the wrinkles <u>on</u> his forehead TPP(x, y) ∧ sfsi(x, y)

the house <u>on</u> the river EC(x, y)

the boat <u>on</u> the river NTPP(x, y)

the boy jumped <u>over</u> the wall DC(x, y) ∧ rlll(x, y)

Joan nailed a board <u>over</u> the hole in the ceiling EC(x, y) ∧ iebe(x, y)

he walked <u>around</u> the pool DC(x, y) ∧ rrll(x, y)

he swam <u>around</u> the pool TPP(x, y) ∧ rrll(x, y)

the house is <u>north</u> of this tree N_NE_E(x, y)

he is <u>behind</u> the house lf(x, y, v)

TPP = in RCC-8 (regions)

iebe = below DC_{69} (lines)

rlll = above DC_{24}

sfsi = front DC_{69}

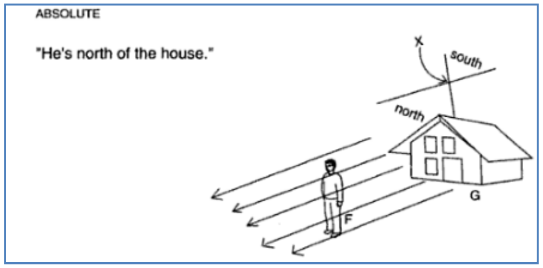
N_NE_E = north CDC_{511} (regions)

lf = behind DCC_{17} (points)

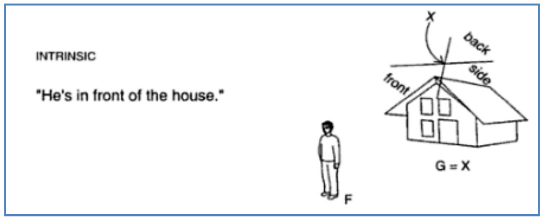
rrll = parallel DC_{24}

Orientation: Summary

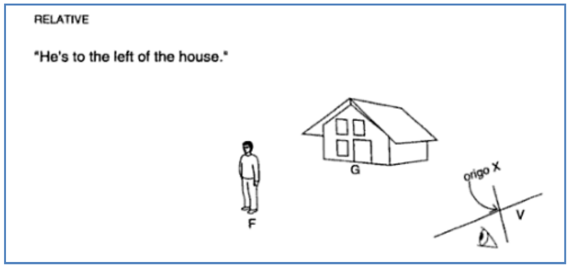
- The three frames of reference can be mapped to particular spatial representations with well-defined properties (points, lines, regions)
- An NLP system for a given language will need to know much more about the specifics of how the language expresses orientation
  - Which frames of reference are used in a particular language
  - Which frames are involved in a particular use
    - Can this be information be acquired from/tested against corpora?



CDC_{511}



DC_{24} DC_{69} DC_{77}
$OPRA_{20}$

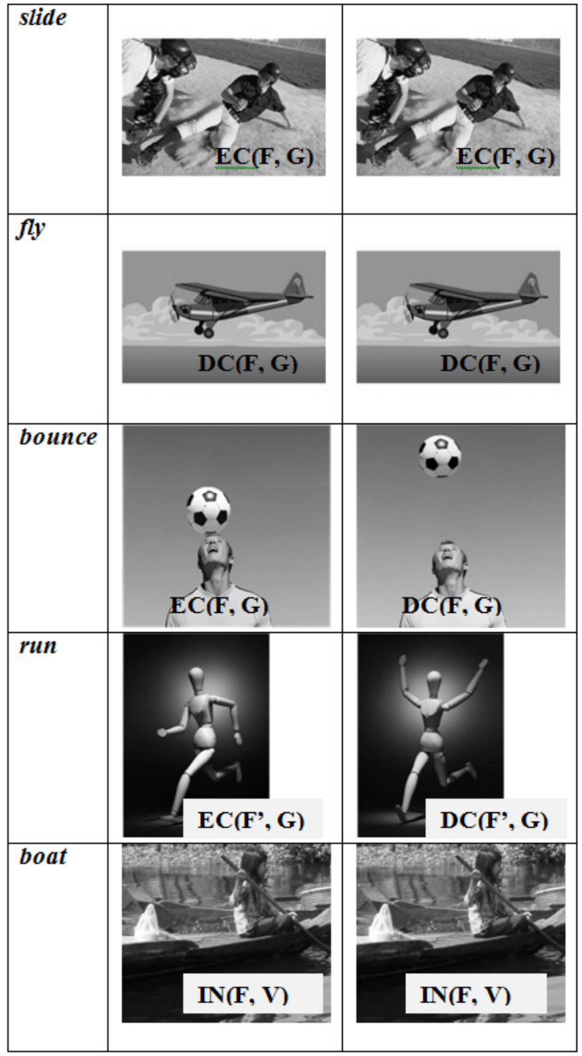


DCC_{17}

Problems with Qualitative Models of Spatial Configurations

- Reasoning in any one of these representations is not always tractable
- Need to combine representations from both topology and orientation
  - *We climbed over the mountains, and then descended to the east, where a thick green rainforest grew up around the road.*
    - Here *over* means both topological disconnection (EC in RCC-8) and the orientation of 'above'. Likewise, *around* involves both disconnection and parallelism.
  - *upper-left, front-upper-left* (mix of absolute and intrinsic)
- Research is underway on methods of formally combining representations,
  - RCC-8 and CDC (Liu et al. 2009).
  - Bipath-consistency (Gerevini and Renz 1998)
- Need to consider higher-dimensional representations for objects
  - So far, only considered 2D points, lines, and regions

Motion Verbs as Sequences of Spatial Configurations



→ Time

Time Intervals as 1D Regions

- A set of instants I is an **interval** iff I is a convex set, i.e., I has the property that $\forall x \forall y \in I$ and $\forall t \in \Re$, if $x \leq t \leq y$ then $t \in I$.
  - In other words, any subinterval of I includes anything inside it.
  - Thus, intervals will not have gaps or holes in them.
- Restrict intervals to be non-empty
- 13 basic relations between intervals
- 2^{13} combinations

Interval Calculus

(Allen 1984)

RELATION	ILLUSTRATION	SYMBOL
A is EQUAL to B	AAA BBB	=
A is BEFORE B, B is AFTER A	AAA BBB	<. >
A MEETS B, B is MET by A	AAABBB	m. mi
A OVERLAPS B, B is OVERLAPPED by A	AAAA BBBB	o, oi
A STARTS B, B is STARTED by A	AAA BBBBBB	s, si
A FINISHES B, B is FINISHED by A	AAA BBBBBB	f, fi
A DURING B, B CONTAINS A	AAA BBBBBB	d, di

B r2 C A r1 B	<	>	d	di	o	oi	m	mi	s	si	f	fi
"before" <	<	no info	< o m d s	<	<	< o m d s	<	< o m d s	<	<	< o m d s	<
"after" >	no info	>	> oi mi d f	>	> oi mi d f	>	> oi mi d f	>	> oi mi d f	>	>	>
"during" d	<	>	d	no info	< o m d s	> oi mi d f	<	>	d	> oi mi d f	d	< o m d s
"contains" di	< o m di fi	> oi di mi si	o oi dur con =	di	o di fi	oi di si	o di fi	oi di si	di fi o	di	di si oi	di
"overlaps" o	<	> oi di mi si	o d s	< o m di fi	< o m	o oi dur con =	<	oi di si	o	di fi o	d s o	< o m
"over-lapped-by" oi	< o m di fi	>	oi d f	> oi mi di si	o oi dur con =	> oi mi	o di fi	>	oi d f	oi > mi	oi	oi di si
"meets" m	<	> oi mi di si	o d s	<	<	o d s	<	f fi =	m	m	d s o	<
"met-by" mi	< o m di fi	>	oi d f	>	oi d f	>	s si =	>	d f oi	>	mi	mi
"starts" s	<	>	d	< o m di fi	< o m	oi d f	<	mi	s	s si =	d	< m o
"started by" si	< o m di fi	>	oi d f	di	o di fi	oi	o di fi	mi	s si =	si	oi	di
"finishes" f	<	>	d	> oi mi di si	o d s	> oi mi	m	>	d	> oi mi	f	f fi =
"finished-by" fi	<	> oi mi di si	o d s	di	o	oi di si	m	si oi di	o	di	f fi =	fi

NL Expressions & Interval Calculus

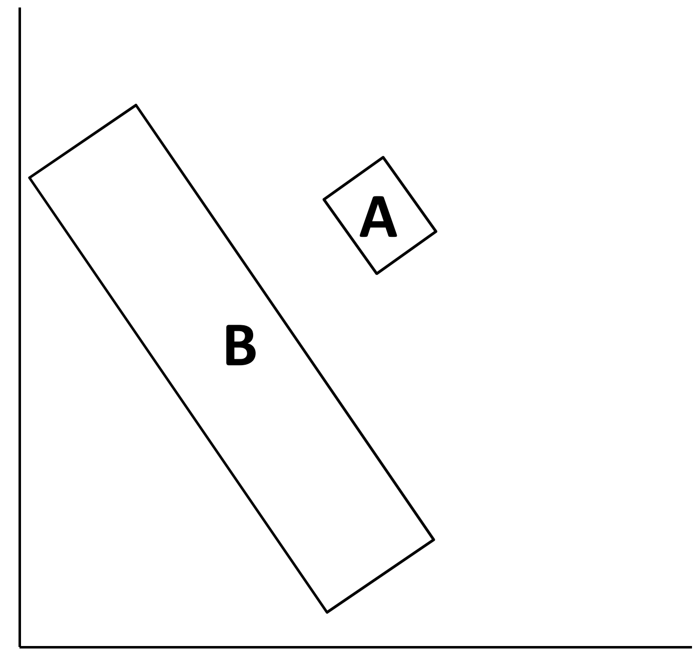
Temporal Expression	**Interval Calculus**
after, follows, previous, soon after	>
ahead of, before, in anticipation of, since then, thereafter	<
as of	o, >
during	d
finishes	f
overlaps, so far, throughout	o
starts	s
while	d, =

RCC-8 & Interval Calculus

RCC-8 Relation	**Interval Calculus Relation**
DC	<, >
EC	m, mi
EQ	=
NTPP	d
TPP	s, f
NTPPi	di
TPPi	si, fi
PO	o, oi

Interval Calculus as 2D Representation?

- Consider case where A and B are non-orthogonal with respect to axes
- Projection on x-axis of A is DURING projection of B on that axis
- Projection on y-axis of A is DURING projection of B on that axis
- But A is NOT DURING (i.e., NTPP) B.



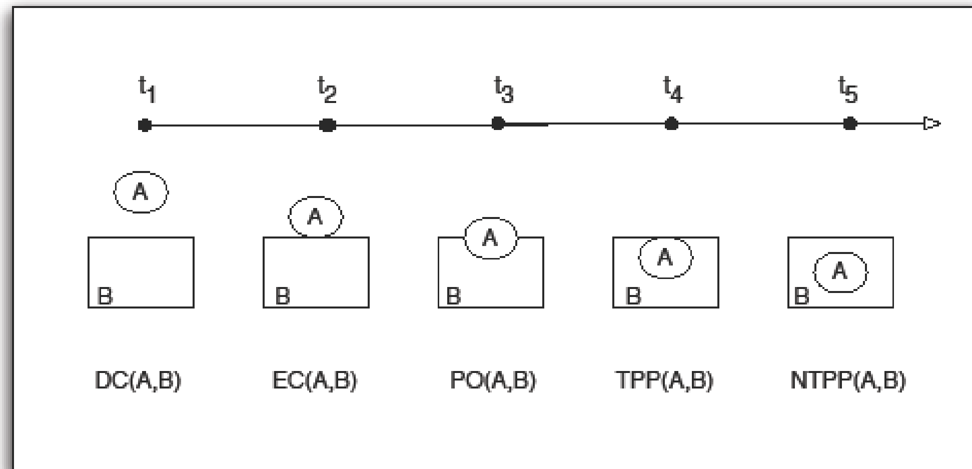
Extending Previous Calculi for Motion

- RCC-8: (Galton 2000)
- 9IC: $9I^+$ (Kurata and Egenhofer 2007)
- RCC-8 and Double-Cross Calculus: Qualitative Trajectory Calculus (QTC) (Van de Weghe 2004)

RCC-8 Extensions: Galton (2000)

- *Spatial Config:* RCC-8 relation holding in a state
- *Motion:* Transitions from an RCC-8 relation holding in one state to an RCC-8 relation holding in another state
  - *enter*: DC(A, B) holds at point t_1, separated by an interval, [t_2, t_4], after which the relation NTTP(A, B) holds at point t_5:
    - *$Trans^{tit}_{I}$ (DC(A, B), NTPP(A, B))*
- But does not provide compositional semantics for motion expressions

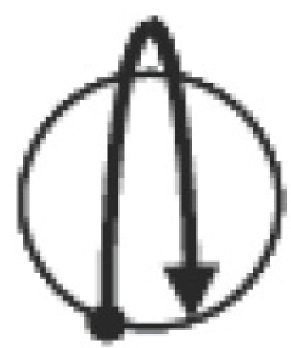
enter



Basic 9I^{+} (Kurata and Egenhofer 2007)

- *Spatial Config*: intersection of start $\delta_S L$ and end $\delta_E L$ of directed line L with region R
- *Motion:* (*B*, *IBEBI*, *B*):
    1. A starts at the Boundary
    2. A moves to the Interior
    3. A touches the Boundary
    4. A move to the Exterior
    5. A touches the Boundary
    6. A enters the Interior
    7. A touches the Boundary
- But doesn't provide temporal indices

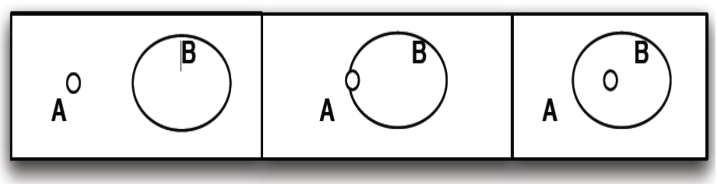
$$\begin{pmatrix} L^{\circ} \cap R^{\circ} & L^{\circ} \cap \delta R & L^{\circ} \cap R^{-} \\ \delta_S L \cap R^{\circ} & \delta_S L \cap \delta R & \delta_S L \cap R^{-} \\ \delta_E L \cap R^{\circ} & \delta_E L \cap \delta R & \delta_E L \cap R^{-} \\ L^{-} \cap R^{\circ} & L^{-} \cap \delta R & L^{-} \cap R^{-} \end{pmatrix}$$



Extending 9I$^+$ (1)

- *Spatial Config:* intersection of a point with a region R, its boundary δR, its interior R^o or its exterior R^-
- *Motion:* configurations at successive temporal indices

$$\begin{pmatrix} t1 & t2 & t3 \\ P_1 \cap R_1^- & P_1 \cap \delta R_1 & P_1 \cap R_1^\circ \\ P_2 \cap R_2^- & P_2 \cap \delta R_2 & P_2 \cap R_2^\circ \\ P_3 \cap R_3^- & P_3 \cap \delta R_3 & P_3 \cap R_3^\circ \end{pmatrix}$$



$$\begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

enter

Extending 9I$^+$ (2)

$$\begin{pmatrix} t1 & t2 & t3 \\ P_1 \cap R_1^- & P_1 \cap \delta R_1 & P_1 \cap R_1^\circ \\ P_2 \cap R_2^- & P_2 \cap \delta R_2 & P_2 \cap R_2^\circ \\ P_3 \cap R_3^- & P_3 \cap \delta R_3 & P_3 \cap R_3^\circ \end{pmatrix}$$

$$\underset{\textit{enter}}{\begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix}} \quad \underset{\textit{arrive}}{\begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 1 & 0 \end{pmatrix}} \quad \underset{\textit{exit}}{\begin{pmatrix} 0 & 0 & 1 \\ 0 & 1 & 0 \\ 1 & 0 & 0 \end{pmatrix}} \quad \underset{\textit{leave}}{\begin{pmatrix} 0 & 1 & 0 \\ 1 & 0 & 0 \\ 1 & 0 & 0 \end{pmatrix}}$$

QTC

Previous Models of Motion

- Do not represent *disconnected from* (DC) relations
- Do not capture movement towards or away from, as well as relative movement between two objects

QTC_{Basic}

- *Spatial Config:*
  - 1. All objects participate in the DC relation only.
  - 2. There are only two objects captured by the model.
  - 3. Objects are represented as points, i.e., 0D objects.
  - 4. Objects move in 1D only.
- *Motion:*
  - Consider a **trajectory pair** involving the relative change in position of objects x and y at two time points, t_1 and t_2

Models of Relative Motion (Weghe et al 2005)

Basic QTC (QTC_B) makes a set of simplifications in order to make the computation tractable.

(37) 1. All objects participate in the DC relation only.
2. There are only two objects captured by the model.
3. Objects are represented as points, 0D objects.
4. Objects move in 1D only.

(38) a. Value '$-$' for object x: the proximity of x is decreasing relative to object y.
b. Value '0' for object x: the proximity of x is constant relative to object y.
c. Value '$+$' for object x: the proximity of x is increasing relative to object y.

Models of Relative Motion (Weghe et al 2005)

This captures notion of the trajectory of two objects moving away from each other. The complete set of the nine QTC_B trajectory relations is given below.

(39) 1. $(-,-)$: two objects are *moving away from each other*.
2. $(-,0)$: the left object is *moving away from the right object*.
3. $(-,+)$: the right object is *following the left object*.
4. $(0,-)$: the right object is *moving away from the left object*.
5. $(0,0)$: two objects are *stationary relative to each other*.
6. $(0,+)$: the right object is *approaching the left object*.
7. $(+,-)$: the left object is *following the right object*.
8. $(+,0)$: the left object is *approaching the right object*.
9. $(+,+)$: two objects are *moving towards each other*.

Models of Relative Motion (Weghe et al 2005)

To illustrate the spatial change inherent in the encoded trajectory pairs, consider a visualization of $(-,-)$ for two objects, k and l, shown below in Figure 3.

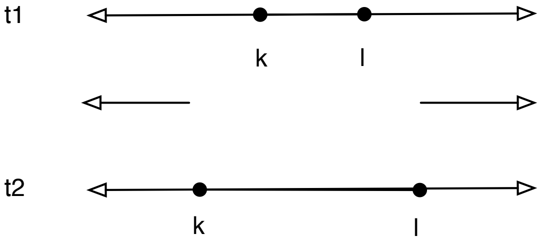


Figure: QTC_B relation $(-,-)$

Models of Relative Motion (Weghe et al 2005)

The complete icon set of the nine QTC_B trajectory relations is shown below.

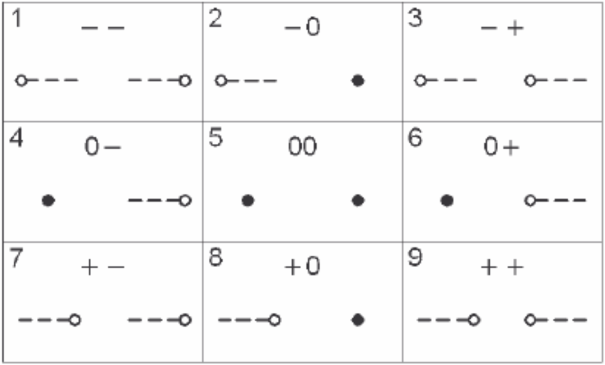
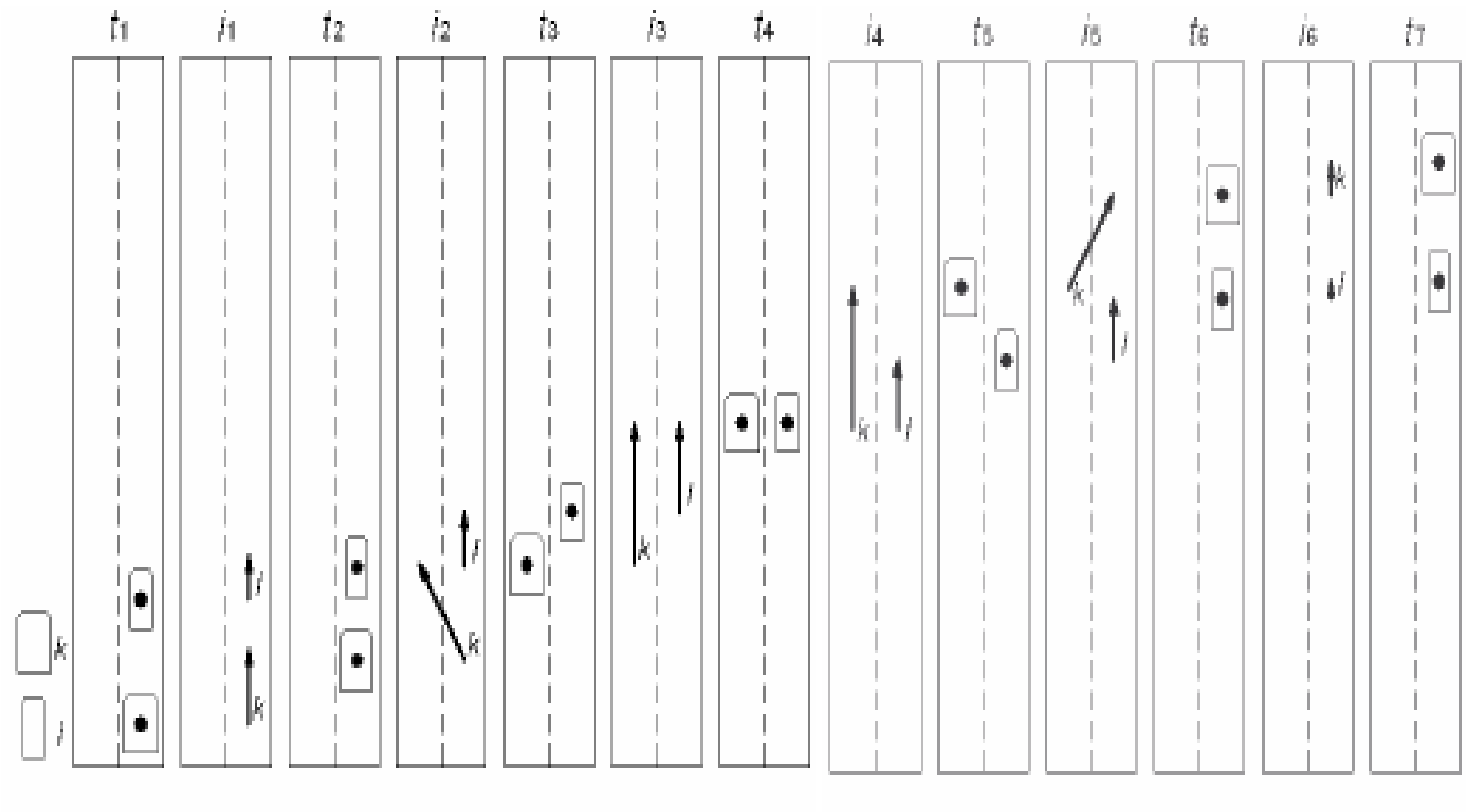


Figure: The 9 QTC_B trajectory relations

overtake in QTC



QTC Assessment

- Addresses relative motion, where both figure and ground are potentially moving in either 1D or 2D.
- Handles metric incremental motion towards an object (*approach*), as well as tracking the motion of two objects (*follow* and *chase*).
- Does not integrate directly into a conventionally compositional semantics.

Conclusion

- Topological and orientation meaning of spatial prepositions can be represented in terms of calculi involving spatial configurations of two or three objects: figure, ground and (for orientation relative frame) viewer
  - Here objects are represented as points, lines, and regions
- Meaning of motion verbs can be captured in terms of qualitative spatiotemporal calculi involving temporal sequences of spatial configurations
- These calculi require further integration with each other and need to be constrained for efficiency
- Next section: a qualitative calculus that provides a compositional semantics for motion verbs

Semantics of Motion Expressions

40 Minutes

Outline

- Representing Spatial Concepts Linguistically
- Qualitative Spatial Reasoning (QSR)
- QSR Applied to Motion
- Representing Motion Dynamically in Language
- Motion Update Phenomena in Discourse
- Implementing Motion Update with Metric Grounding
- Accounting for Spatial Configurations

Representing Space in Language

(1) a. Spatial Prepositions and Particles: *on*, *in*, *under*, *over*, *up*, *down*, *left of*;
b. Verbs of Position and Movement: *lean over*, *sit*, *run*, *swim*, *arrive*;
c. Spatial Attributes: *tall*, *long*, *wide*, *deep*;
d. Spatial Nominals: *area*, *room*, *center*, *corner*, *front*, *hallway*.
e. Shape Classifiers: *river (as line)*, *river (as connection)*, *flat*, *round*

Selecting Spatial Properties

- Semantic Type: Position and Posture verbs: *lean*, *hunch over*
- Argument Selection: *fill*, *wipe*, *cover*, *leave*, *enter*
  wipe the table, *erase the whiteboard*
  enter the room, *leave the party*

Formal Foundations for Spatial Representation

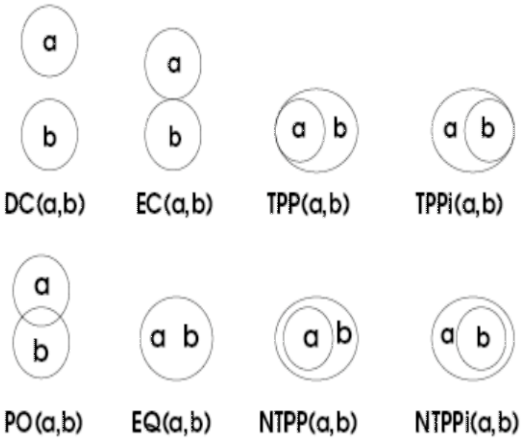
- Egenhofer (1991)
- Randell, Cui and Cohn (1992)
- Ligozat (1992)
- Freksa (1992)
- Galton (1993)
- Asher and Vieu (1995), Asher and Sablayrolles (1995)
- Gooday and Galton (1997)
- Muller (1998)

Region Connection Calculus (RCC8)

(2) a. Disconnected (DC): A and B do not touch each other.
b. Externally Connected (EC): A and B touch each other at their boundaries.
c. Partial Overlap (PO): A and B overlap each other in Euclidean space.
d. Equal (EQ): A and B occupy the exact same Euclidean space.
e. Tangential Proper Part (TPP): A is inside B and touches the boundary of B.
f. Non-tangential Proper Part (NTPP): A is inside B and does not touch the boundary of B.
g. Tangential Proper Part (TPPi): B is inside A and touches the boundary of A.
h. Non-tangential Proper Part Inverse (NTPPi): B is inside A and does not touch the boundary of A.

Region Connection Calculus (RCC8)

Region Connection Calculus (RCC8)



- These 8 JEPD relations describe topological relationships.

Examples of RCC8 Relations

(3) a. A touches B.
$EC(A, B)$
b. A does not touch B. /A is separated from B.
$DC(A, B)$

(4) a. The glass is on the table.
$[glass(G) \wedge table(T) \wedge EC(G, T)]$
b. The glass is not on the table.
$[glass(G) \wedge table(T) \wedge DC(G, T)]$

Problems with RCC8 Relations

(5) a. The glass is on the table.
$[glass(G) \wedge table(T) \wedge EC(G, T) \wedge OVER(G, T)]$
b. The smoke alarm is on the ceiling.
$[alarm(A) \wedge ceiling(C) \wedge EC(A, C) \wedge UNDER(A, C)]$
c. The picture is on the wall.
$[picture(P) \wedge wall(W) \wedge EC(P, W) \wedge NEXT\_TO(P, W)]$

(6) a. The price tag is on the table (on the leg).
b. There's blue paint on the table (on the edge).

(7) a. The box is in the middle of the room.
$[box(B) \wedge room(R) \wedge NTPP(B, R)]$
b. Milk is the glass.
$[milk(M) \wedge glass(G) \wedge TPP(M, G)]$

Spatial Relations in Motion Predicates

Spatial Relations in Motion Predicates

- Topological Path Expressions

Spatial Relations in Motion Predicates

- Topological Path Expressions
  arrive, leave, exit, land, take off

Spatial Relations in Motion Predicates

- Topological Path Expressions
  arrive, leave, exit, land, take off
- Orientation Path Expressions

Spatial Relations in Motion Predicates

- Topological Path Expressions
  arrive, leave, exit, land, take off
- Orientation Path Expressions
  climb, descend

Spatial Relations in Motion Predicates

- Topological Path Expressions
  arrive, leave, exit, land, take off
- Orientation Path Expressions
  climb, descend
- Topo-metric Path Expressions

Spatial Relations in Motion Predicates

- Topological Path Expressions
  arrive, leave, exit, land, take off
- Orientation Path Expressions
  climb, descend
- Topo-metric Path Expressions
  approach, near, distance oneself

Spatial Relations in Motion Predicates

- Topological Path Expressions
  arrive, leave, exit, land, take off
- Orientation Path Expressions
  climb, descend
- Topo-metric Path Expressions
  approach, near, distance oneself
- Topo-metric orientation Expressions

Spatial Relations in Motion Predicates

- Topological Path Expressions
  arrive, leave, exit, land, take off
- Orientation Path Expressions
  climb, descend
- Topo-metric Path Expressions
  approach, near, distance oneself
- Topo-metric orientation Expressions
  just below, just above

Language Data

Language Data

- Manner construction languages

Language Data

- Manner construction languages
  Path information is encoded in directional PPs and other adjuncts, while verb encode manner of motion
  English, German, Russian, Swedish, Chinese

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Language Data

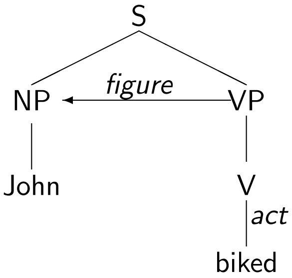
- Manner construction languages
  Path information is encoded in directional PPs and other adjuncts, while verb encode manner of motion
  English, German, Russian, Swedish, Chinese
- Path construction languages
  Path information is encoded in matrix verb, while adjuncts specify manner of motion
  Modern Greek, Spanish, Japanese, Turkish, Hindi

Defining Motion (Talmy 1985)

(8) a. The *event* or situation involved in the change of location ;
b. The object (construed as a point or region) that is undergoing movement (the *figure*);
c. The region (or *path*) traversed through the motion;
d. A distinguished point or region of the path (the *ground*);
e. The *manner* in which the change of location is carried out;
f. The *medium* through which the motion takes place.

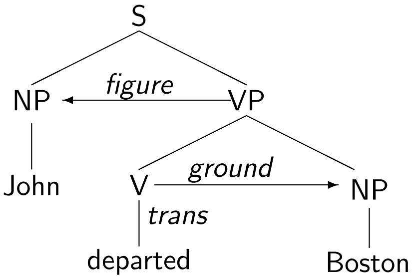
Manner Predicates

(9)



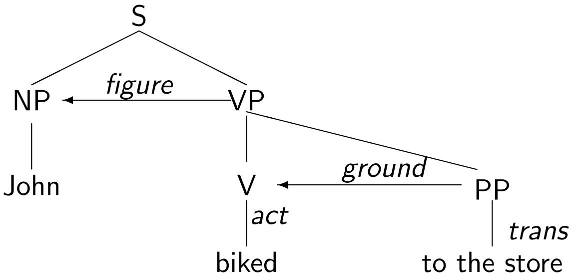
Path Predicates

(10)



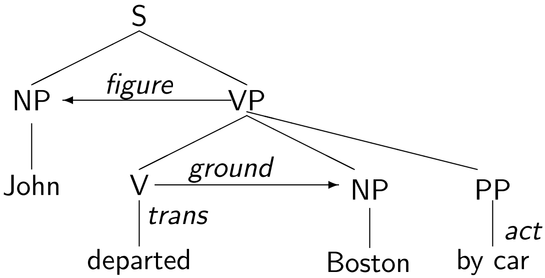
Manner with Path Adjunction

(11)



Path with Manner Adjunction

(12)



Path+manner Predicates (Talmy 2000) 1/2

(13) a. Isabel climbed for 15 minutes.
b. Nicholas fell 100 meters.

(14) a. There is an action (e) bringing about an iterated non-distinguished change of location;
b. The figure undergoes this non-distinguished change of location;
c. The figure creates (leaves) a path by virtue of the motion.
d. The action (e) is performed in a certain manner.
e. The path is oriented in an identified or distinguished way.

Path+manner Predicates (Talmy 2000) 2/2

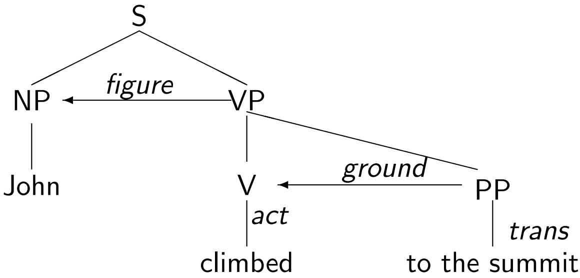
Unlike pure manner verbs, this class of predicates admits of two compositional constructions with adjuncts.

(15) **Manner of motion verb with path adjunct;**
John climbed to the summit.

(16) **Manner of motion verb with path argument;**
John climbed the mountain.

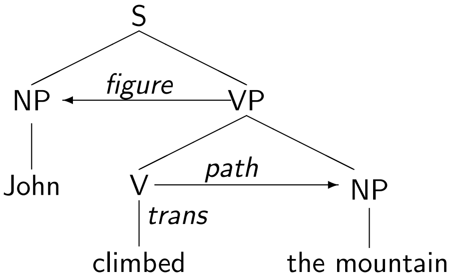
With Path Adjunct

(17)



With Path Argument

(18)



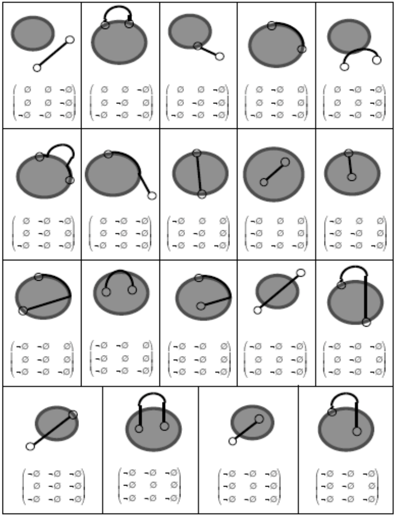
9-Intersection Model for Line-Region Relations Egenhofer and Herring (1991)

Characterized by the topological relations between two point sets, A and B, and the set intersections of their interior, boundary, and exterior:

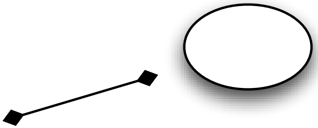
(i) Region interior: R^o
(ii) Region boundary: ∂R
(iii) Region exterior: R^-

$$I(A,B) = \begin{pmatrix} A^o \cap B^o & A^o \cap \partial B & A^o \cap B^- \\ \partial A \cap B^o & \partial A \cap \partial B & \partial A \cap B^- \\ A^- \cap B^o & A^- \cap \partial B & A^- \cap B^- \end{pmatrix}$$

Line-Region Intersection in 9IC

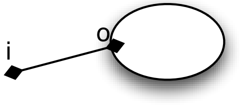


Line-Region Intersection



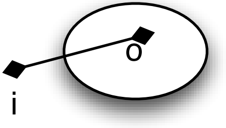
$$\begin{pmatrix} 0 & 0 & 1 \\ 0 & 0 & 1 \\ 1 & 1 & 1 \end{pmatrix}^{(LR11)}$$

Line-Region Intersection



$$\begin{pmatrix} 0 & 0 & 1 \\ 0 & 1 & 1 \\ 1 & 1 & 1 \end{pmatrix}^{(LR13)}$$

Line-Region Intersection



$$\begin{pmatrix} 1 & 1 & 1 \\ 1 & 0 & 1 \\ 1 & 1 & 1 \end{pmatrix}^{(LR75)}$$

Dynamic LR-Intersection Model

cf. Kurata and Egenhofer (2007): Directed Line-Region Intersection

Assume the intersection relations for a region, R, and a line, L, with two distinguished boundaries instead of one:

- left-boundary: $\partial_L L$,
- right-boundary: $\partial_R L$

Let the relation, I^e (e.g., intersection with distinguished endpoints) be defined as the intersection of a region, R, and a two-boundaried line, L, where :

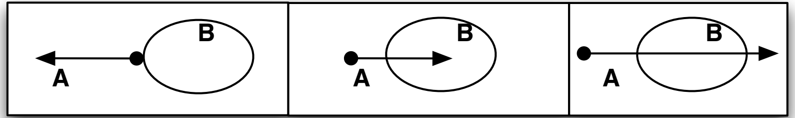
$$I^e(L,R) = \begin{pmatrix} L^o \cap R^o & L^o \cap \partial R & L^o \cap R^- \\ \partial_L L \cap R^o & \partial_L L \cap \partial R & \partial_L L \cap R^- \\ \partial_R L \cap R^o & \partial_R L \cap \partial R & \partial_R L \cap R^- \\ L^- \cap R^o & L^- \cap \partial R & L^- \cap R^- \end{pmatrix}$$

Dynamic LR-Intersection Model

So $LR13$ has an I^e value represented as the following:

$$\begin{pmatrix} 0 & 0 & 1 \\ 0 & 0 & 1 \\ 0 & 1 & 0 \\ 1 & 1 & 1 \end{pmatrix}^{(LR13^e)}$$

Direct LR Relations: Egenhofer and Herring (1991)



The road starts at the park.

The road enters the park.

The road goes through the park.

Figure: Directed Line-region examples

Interpreting Motion in the LR-Intersection Model

A specific matrix can be viewed as encoding the value of intersective relations from multiple states. These state values are overlays on top of each other.

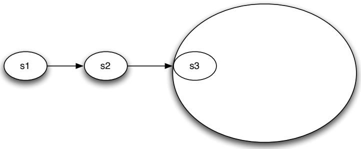
Motion can now be read off of the matrix as a Temporal Trace (e.g., ordering) of LR Intersection cell values:

We will model the "object in motion" as the topological transformations over the line, indexed through a temporal trace.

For example, $LR13^e$ encodes two path predicates:

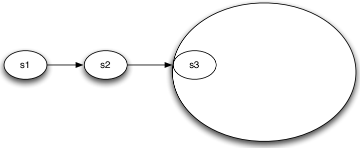
- $[\![land]\!]_{LR13^e}$:
  $\langle [\partial_L L \cap \partial R = 0]@s_1, [L^o \cap \partial R = 0]@s_2, [\partial_R L \cap \partial R = 1]@s_3 \rangle$;
- $[\![take\ off]\!]_{LR13^e}$:
  $\langle [\partial_R L \cap \partial R = 1]@s_1, [L^o \cap \partial R = 0]@s_2, [\partial_L L \cap \partial R = 0]@s_3 \rangle$;

Dynamic LR-Intersection Model: land



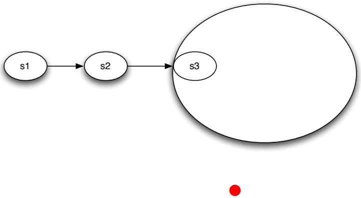
$$I^e(L,R) = \begin{pmatrix} L^o \cap R^o = 0 & L^o \cap \partial R = 0 & L^o \cap R^- = 1 \\ \partial_L L \cap R^o = 0 & \partial_L L \cap \partial R = 0 & \partial_L L \cap R^- = 1 \\ \partial_R L \cap R^o = 0 & \partial_R L \cap \partial R = 1 & \partial_R L \cap R^- = 0 \\ L^- \cap R^o = 1 & L^- \cap \partial R = 1 & L^- \cap R^- = 1 \end{pmatrix}^{(LR13^e)}$$

Dynamic LR-Intersection Model: land



$$I^e(L,R) = \begin{pmatrix} L^o \cap R^o = 0 & L^o \cap \partial R = 0 & L^o \cap R^- = 1 \\ \partial_L L \cap R^o = 0 & \partial_L L \cap \partial R = 0 & \partial_L L \cap R^- = 1 \\ \partial_R L \cap R^o = 0 & \partial_R L \cap \partial R = 1 & \partial_R L \cap R^- = 0 \\ L^- \cap R^o = 1 & L^- \cap \partial R = 1 & L^- \cap R^- = 1 \end{pmatrix}^{(LR13^e)}$$

Dynamic LR-Intersection Model: land



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Dynamic LR-Intersection Model

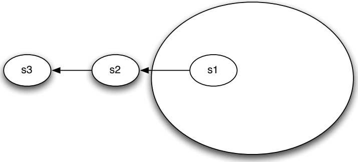
$LR75$ has an I^e value represented as the following:

$$\begin{pmatrix} 1 & 1 & 1 \\ 0 & 0 & 1 \\ 1 & 1 & 0 \\ 1 & 1 & 1 \end{pmatrix}^{(LR75^e)}$$

$LR75^e$ encodes several path predicates:

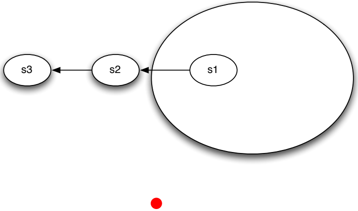
- $[\![arrive]\!]_{LR13^e}$:
  $\langle [\partial_L L \cap \partial R = 0]@s_1, [L^o \cap \partial R = 0]@s_2, [\partial_R L \cap \partial R = 1]@s_3 \rangle$;
- $[\![exit]\!]_{LR13^e}$:
  $\langle [\partial_R L \cap \partial R = 1]@s_1, [L^o \cap \partial R = 0]@s_2, [\partial_L L \cap \partial R = 0]@s_3 \rangle$;

Dynamic LR-Intersection Model: leave



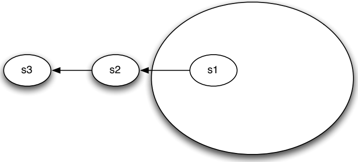
$$\begin{pmatrix} 1 & 1 & 1 \\ 0 & 0 & 1 \\ \color{red}{1} & 1 & 0 \\ 1 & 1 & 1 \end{pmatrix}^{(LR75^e)}$$

Dynamic LR-Intersection Model: leave



$$\begin{pmatrix} 1 & 1 & 1 \\ 0 & 0 & 1 \\ 1 & 1 & 0 \\ 1 & 1 & 1 \end{pmatrix}^{(LR75^e)}$$

Dynamic LR-Intersection Model: leave



•

$$\begin{pmatrix} 1 & 1 & 1 \\ 0 & 0 & 1 \\ 1 & 1 & 0 \\ 1 & 1 & 1 \end{pmatrix}^{(LR75^e)}$$

Metric Extensions to Dynamic LR-Intersection Model

- Splitting: determines how the R and L boundaries, interiors, and exteriors are cut.

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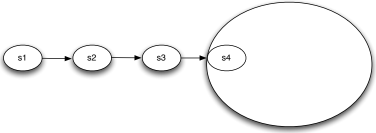
- Closeness: determines how far apart the region's boundary is from the line.
- Metric relations capture predicates such as *approach*, *pull away from*.

  a. The car approached the building.

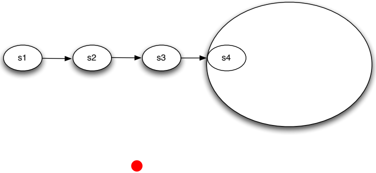
  b. The car pulled away from the sidewalk.

Dynamic LR-Intersection Model: approach



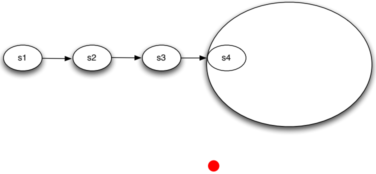
$$I^e(L,R) = \begin{pmatrix} L^o \cap R^o = 0 & L^o \cap \partial R = 0 & L^o \cap R^- = 1 \\ \partial_L L \cap R^o = 0 & \partial_L L \cap \partial R = 0 & \partial_L L \cap R^- = 1 \\ \partial_R L \cap R^o = 0 & \partial_R L \cap \partial R = 1 & \partial_R L \cap R^- = 0 \\ L^- \cap R^o = 1 & L^- \cap \partial R = 1 & L^- \cap R^- = 1 \end{pmatrix} \quad (LR13^e)$$

Dynamic LR-Intersection Model: approach



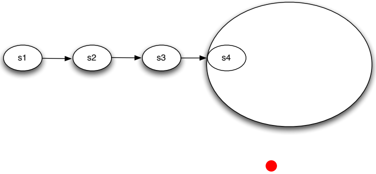
$$I^e(L,R) = \begin{pmatrix} L^o \cap R^o = 0 & L^o \cap \partial R = .3 & L^o \cap R^- = 1 \\ \partial_L L \cap R^o = 0 & \partial_L L \cap \partial R = 0 & \partial_L L \cap R^- = 1 \\ \partial_R L \cap R^o = 0 & \partial_R L \cap \partial R = 1 & \partial_R L \cap R^- = 0 \\ L^- \cap R^o = 1 & L^- \cap \partial R = 1 & L^- \cap R^- = 1 \end{pmatrix} \quad (LR13^e)$$

Dynamic LR-Intersection Model: approach



$$I^e(L,R) = \begin{pmatrix} L^o \cap R^o = 0 & L^o \cap \partial R = .6 & L^o \cap R^- = 1 \\ \partial_L L \cap R^o = 0 & \partial_L L \cap \partial R = 0 & \partial_L L \cap R^- = 1 \\ \partial_R L \cap R^o = 0 & \partial_R L \cap \partial R = 1 & \partial_R L \cap R^- = 0 \\ L^- \cap R^o = 1 & L^- \cap \partial R = 1 & L^- \cap R^- = 1 \end{pmatrix}^{(LR13^e)}$$

Dynamic LR-Intersection Model: approach



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Galton Use of RCC8 for Decomposition of enter

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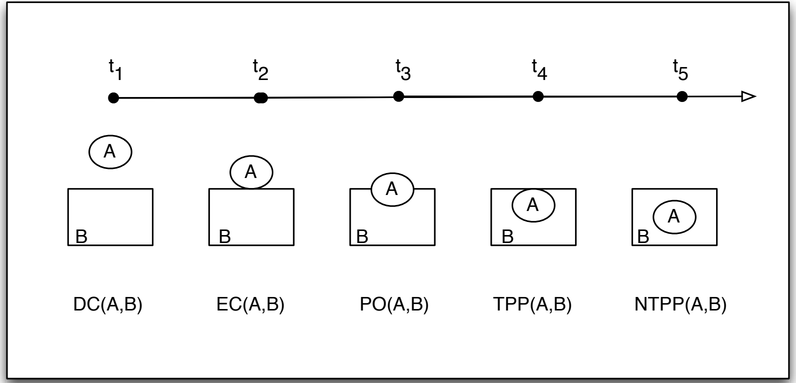

Problems with QSR Treatments

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- No compositional behavior for the semantics of language.
- Expressive coverage is weakly sufficient at best.
- Spatial relations in language are rarely just spatial.

Capturing Motion as Change in Spatial Relations

Dynamic Interval Temporal Logic

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- Manner of motion verbs iterate a change in location from state to state.

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  The change in value is tested.
- Manner of motion verbs iterate a change in location from state to state.
  The value is assigned and reassigned.

Event Structure (Pustejovsky 1991)

(19) a. EVENT $\rightarrow$ STATE | PROCESS | TRANSITION

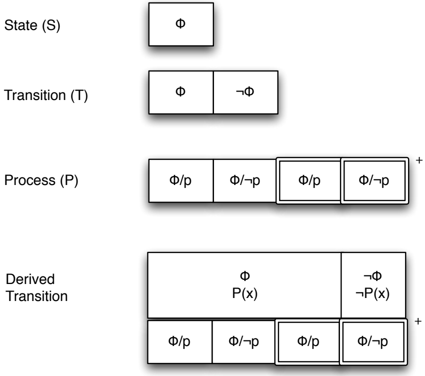
b. STATE: $\rightarrow$ e

c. PROCESS: $\rightarrow$ $e_1 \ldots e_n$

d. TRANSITION_{ach}: $\rightarrow$ STATE STATE

e. TRANSITION_{acc}: $\rightarrow$ PROCESS STATE

Frame-based Event Structure (Pustejovsky, 2012)



Frame-based Event Structure

Assume that a *state* is a single frame structure, wherein a proposition is interpreted at temporal index i:

(20) $\boxed{\phi}_i$

Concatenation can apply to two or more indexes, denoted by the interval $[i, j]$:

(21) $\boxed{\phi}_i \boxed{\phi}_j = \boxed{\phi}_{\langle i,j \rangle}$

We define a *transition* as a sequence containing a propositional opposition over adjacent states. From a *2-state transition*,

(22) $\boxed{\phi}\boxed{\neg\phi}_{\langle i,i+1 \rangle}$

we can compose *extended transitions*:

(23) $\boxed{\phi}_{[i,j]} \boxed{\neg\phi}_{j+1} = \boxed{\phi}\boxed{\neg\phi}_{\langle [i,j],j+1 \rangle}$

Dynamic Interval Temporal Logic: LTL

(24) a. $\langle \mathcal{M}, i \rangle \models \phi$

"ϕ holds at time i"

b. $\langle \mathcal{M}, i \rangle \models \bigcirc\phi$ iff $\langle \mathcal{M}, i+1 \rangle \models \phi$

"ϕ holds at the next time."

c. $\langle \mathcal{M}, i \rangle \models \Diamond\phi$ iff $\exists j[i \leq j \wedge \langle \mathcal{M}, j \rangle \models \phi]$

"ϕ holds at some time in the future."

d. $\langle \mathcal{M}, i \rangle \models \Box\phi$ iff $\forall j[i \leq j \rightarrow \langle \mathcal{M}, j \rangle \models \phi]$

"ϕ holds for every time in the future."

e. $\langle \mathcal{M}, i \rangle \models \phi\,\mathcal{U}\psi$ iff $\exists j[j \geq i \wedge \langle \mathcal{M}, j \rangle \models \psi$
$\wedge\, \forall k[i \leq k < j \rightarrow \langle \mathcal{M}, k \rangle \models \phi]$

"ϕ holds until ψ starts to hold."

Dynamic Interval Temporal Logic: DL 1/2

(25) a. Any atomic program, a, is a program;

"Execute program a".

$\langle \mathcal{M}, (i, i+1) \rangle \models a$ iff $\langle \mathcal{M}, i \rangle \models s_1 \wedge \langle \mathcal{M}, i+1 \rangle \models s_2$

b. If a and b are atomic programs, then $a; b$ is a compound program called a *sequence*; "Execute a, then execute b";

$\langle \mathcal{M}, (i, j) \rangle \models a; b$ iff

$\exists k[i \leq k \leq j \wedge \langle \mathcal{M}, (i, k) \rangle \models a \wedge \langle \mathcal{M}, (k, j) \rangle \models b]$;

c. If α and β are programs, then $\alpha; \beta$ is a program called a *sequence*; "Execute α, then execute β";

$\langle \mathcal{M}, (i, j) \rangle \models \alpha; \beta$ iff

$\exists k[i \leq k \leq j \wedge \langle \mathcal{M}, (i, k) \rangle \models \alpha \wedge \langle \mathcal{M}, (k, j) \rangle \models \beta]$

d. If ϕ is a formula, then $\phi?$ is a program called a *test*;

"Check the truth value of ϕ, and proceed if ϕ is true, fail if false";

Dynamic Interval Temporal Logic: DL 2/2

(26) e. If a is a program, then a^* is a program called *Kleene iteration*; "Execute a zero or more times."

$$\langle \mathcal{M}, (i, j) \rangle \models a^* \quad \text{iff}$$

$\forall k[i \leq k \leq j \rightarrow \langle \mathcal{M}, (k, k+1) \rangle \models a]$

f. If a is an atomic program and ϕ is a formula, then $[a]\phi$ is a formula;

"It is always the case that after executing a, ϕ is true."

$$\langle \mathcal{M}, (i, i+1) \rangle \models [a]\phi \ \text{ iff } \langle \mathcal{M}, i \rangle \models \bigcirc\phi$$

g. If α is a program and ϕ is a formula, then $[\alpha]\phi$ is a formula;

"It is always the case that after executing α, ϕ is true."

$$\langle \mathcal{M}, (i, j) \rangle \models [\alpha]\phi \ \text{ iff } \langle \mathcal{M}, j-1 \rangle \models \bigcirc\phi$$

Change and Directed Motion

- Manner-of-motion verbs introduce an assignment of a location value:
  $loc(x) := y; y := z$
- Directed motion introduces a dimension that is measured against:
  $d(b, y) < d(b, z)$
- Path verbs introduce a pair of tests:
  $\neg\phi? \ldots \phi?$

The Assignment: Changing Attribute Values 1/2

- Basic assignment:
  If x and y are variables, then $x := y$ is an atomic program.
  "x assumes the value given to y in the next state."
  $\langle \mathcal{M}, (i, i+1), (u, u[x/u(y)]) \rangle \models x := y$
  iff $\langle \mathcal{M}, i, u \rangle \models s_1 \wedge \langle \mathcal{M}, i+1, u[x/u(y)] \rangle \models x = y$

- $change\_loc(x) =_{df} \ loc(x) := y \, ; (y := z, y \neq z)^+$

The Assignment: Changing Attribute Values 2/2

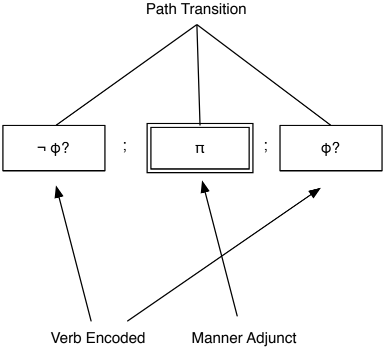
- $\boxed{A(x) := y}\boxed{y := z, y \neq z}^{+}_{\langle i,j\rangle}$

- BASIC CHANGE-OF-ATTRIBUTE:
  $change\_a_{bas}(x) =_{df}\ A(x) := y\,; y := z, y \neq z$
  $\langle \mathcal{M}, (i,j), (u,v)\rangle \models A(x) := y\,; y := z,\ y \neq z$ iff
  $\exists k \exists w[[i \leq k \leq j \wedge (u,w) \wedge (w,v) \wedge \langle \mathcal{M}, (i,k), (u,w)\rangle$
  $\models A(x) := y \wedge \langle \mathcal{M}, (k,j), (w,v)\rangle \models y := z,\ y \neq z]$
- $change\_a(x) =_{df}\ change\_a_{bas}(x); (change\_a_{bas}(x))^{+}$

Change and the Trail it Leaves

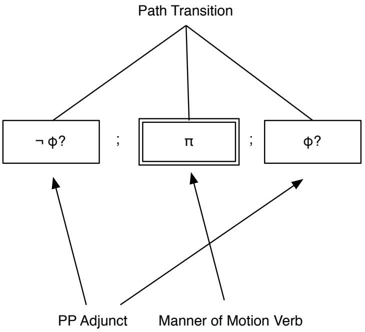
- The execution of a change in the value to an attribute $\mathcal{A}$ for an object x leaves a trail, τ.
- For motion, this trail is the created object of the path p which the mover travels on;
- For creation predicates, this trail is the created object brought about by order-preserving transformations as executed in the directed process above.

Path Verb Construction



- John arrived by foot.
- Mary descended the stairs running.

Manner Verb Construction



- John hopped out of the room.
- Mary crawled to the window.

Directed Motion

Directed Motion

(30) $d(b|t_i, y|t_i) \;<\; d(b|t_{i+1}, z|t_{i+1})$

(31) DIRECTED MOTION:

a. Assign a value, y, to the location of the moving object, x.

$$loc(x) := y$$

b. Name this value b (this will be the beginning of the movement);

$$b := y$$

c. Then, reassign the value of y to z, whose distance from b has increased, $d(b, y) < d(b, z)$;

$$y := z,\; d(b|t_i, y|t_i) \;<\; d(b|t_{i+1}, z|t_{i+1})$$

d. Kleene iterate step (c).

(32) $move_{dir}(x) =_{df} \; loc(x) := y, b := y \,; (y := z, y \neq z, d(b, y) < d(b, z))^+$

Manner of Motion Verbs

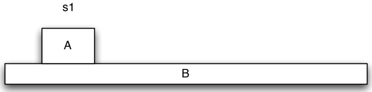
- $[\![walk]\!] = move(x, walk); (move(x, walk)^*$
- $[\![drive]\!] = move(x, drive); (move(x, drive)^*$

Manner as Topological Constraints

Constraints while *move*(x) holds true:
moving object A on a surface B:

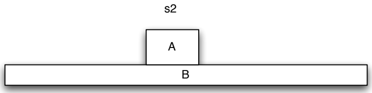
- $[\![slide]\!] =$
  $\langle [\partial A \cap \partial B = 1]@s_i, [\partial A \cap \partial B = 1]@s_{i+1}\rangle$;
- $[\![hop]\!] =$
  $\langle [\partial A \cap \partial B = 1]@s_i, [\partial A \cap \partial B = 0]@s_{i+1}, [\partial A \cap \partial B = 1]@s_{i+2}\rangle$;

Manner as Topological Constraints



- The box slides across the floor.
- $[\![slide]\!] =$
  $\langle [\partial A \cap \partial B = 1]@s_1, [\partial A \cap \partial B = 1]@s_2, [\partial A \cap \partial B = 1]@s_3 \rangle;$

Manner as Topological Constraints



- The box slides across the floor.
- $[\![slide]\!] =$
  $\langle [\partial A \cap \partial B = 1]@s_1, [\partial A \cap \partial B = 1]@s_2, [\partial A \cap \partial B = 1]@s_3 \rangle;$

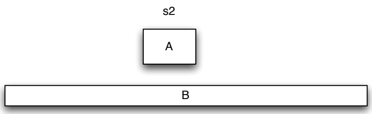
Manner as Topological Constraints

- The box slides across the floor.
- $[\![slide]\!] =$
  $\langle [\partial A \cap \partial B = 1]@s_1, [\partial A \cap \partial B = 1]@s_2, [\partial A \cap \partial B = 1]@s_3 \rangle;$

Manner as Topological Constraints

- The box hops across the floor.
- $\langle[\partial A \cap \partial B = 1]@s_1, [\partial A \cap \partial B = 0]@s_2, [\partial A \cap \partial B = 1]@s_3\rangle$;

Manner as Topological Constraints



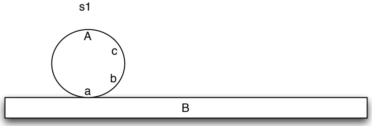
- The box hops across the floor.
- $\langle [\partial A \cap \partial B = 1]@s_1, [\partial A \cap \partial B = 0]@s_2, [\partial A \cap \partial B = 1]@s_3 \rangle;$

Manner as Topological Constraints

- The box hops across the floor.
- $\langle [\partial A \cap \partial B = 1]@s_1, [\partial A \cap \partial B = 0]@s_2, [\partial A \cap \partial B = 1]@s_3 \rangle$;

Manner as Topological Constraints

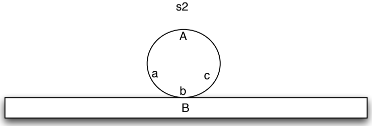
For mereological relations $a \sqsubseteq A$, $a' \sqsubseteq A$:



- The wheel rolls across the floor.
- $\langle [\partial A_a \cap \partial B = 1]@s_1, [\partial A_b \cap \partial B = 1]@s_2, [\partial A_c \cap \partial B = 1]@s_3 \rangle$

Manner as Topological Constraints

For mereological relations $a \sqsubseteq A$, $a' \sqsubseteq A$:



- The wheel rolls across the floor.
- $\langle [\partial A_a \cap \partial B = 1]@s_1, [\partial A_b \cap \partial B = 1]@s_2, [\partial A_c \cap \partial B = 1]@s_3 \rangle$

Manner as Topological Constraints

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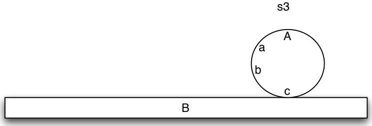

- The wheel rolls across the floor.
- $\langle [\partial A_a \cap \partial B = 1]@s_1, [\partial A_b \cap \partial B = 1]@s_2, [\partial A_c \cap \partial B = 1]@s_3 \rangle$

Path Traversal as Test

- Change-of-state:
  $arrive(x, y) =_{def} \ ((\neg loc(x) = y)?; move(x))^{+}; (loc(x) = y)?$

Path Traversal as Test

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  $to(x, y) =_{def} \; \lambda\pi\lambda x((\neg loc(x) = y)?; \pi(x))^{+}; (loc(x) = y)?$

Path Traversal as Test

- Change-of-state:
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- Manner Composed with Path Test
  John walked to Stanford.

Path Traversal as Test

- Change-of-state:
  $arrive(x, y) =_{def} \; ((\neg loc(x) = y)?; move(x))^{+}; (loc(x) = y)?$
- PP-function:
  $to(x, y) =_{def} \; \lambda\pi\lambda x((\neg loc(x) = y)?; \pi(x))^{+}; (loc(x) = y)?$
- Manner Composed with Path Test
  John walked to Stanford.
  $((\neg loc(j) = s)?; walk(j))^{+}; (loc(x) = s)?$

Path Traversal as Test

- Change-of-state:
  $arrive(x, y) =_{def} \; ((\neg loc(x) = y)?; move(x))^{+}; (loc(x) = y)?$
- PP-function:
  $to(x, y) =_{def} \; \lambda\pi\lambda x((\neg loc(x) = y)?; \pi(x))^{+}; (loc(x) = y)?$
- Manner Composed with Path Test
  John walked to Stanford.
  $((\neg loc(j) = s)?; walk(j))^{+}; (loc(x) = s)?$
- Manner Composed with Initial Assignment and Path Test

Path Traversal as Test

- Change-of-state:
  $arrive(x, y) =_{def} ((\neg loc(x) = y)?; move(x))^+; (loc(x) = y)?$
- PP-function:
  $to(x, y) =_{def} \lambda\pi\lambda x((\neg loc(x) = y)?; \pi(x))^+; (loc(x) = y)?$
- Manner Composed with Path Test
  John walked to Stanford.
  $((\neg loc(j) = s)?; walk(j))^+; (loc(x) = s)?$
- Manner Composed with Initial Assignment and Path Test
  John walked from Menlo Park to Stanford.
  $loc(j) := mp; ((\neg loc(j) = s)?; walk(j))^+; (loc(x) = s)?$

Motion Leaving a Trail

(33) MOTION LEAVING A TRAIL:

a. Assign a value, y, to the location of the moving object, x.

$$loc(x) := y$$

b. Name this value b (this will be the beginning of the movement);

$$b := y$$

c. Initiate a path p that is a list, starting at b;

$$p := (b)$$

d. Then, reassign the value of y to z, where $y \neq z$

$$y := z, y \neq z$$

e. Add the reassigned value of y to path p;

$$p := (p, z)$$

e. Kleene iterate steps (d) and (e);

Directed Motion Leaving a Trail

(34) $move_{dir+tr}(x) =_{df}\ loc(x) := y, b := y, p := (b)\ ; (y := z, y \neq z, p := (p, z), d(b, y) < d(b, z))^{+}$

The compact form for $move_{dir+tr}$ can be illustrated below:

(35) $\boxed{\text{loc}(x) := y, p := (b)}\boxed{\text{loc}(x) := z, y \preccurlyeq z, p := (p, z)}^{+}_{\langle i,j \rangle}$

Leaving a Trail

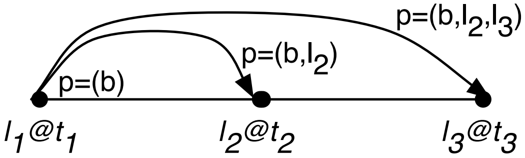


Figure: Directed Motion leaving a Trail

(36) a. The ball rolled 20 feet.

$\exists p \exists x[[roll(x,p) \wedge ball(x) \wedge length(p) = [20, foot]]$

b. John biked for 5 miles.

$\exists p[[bike(j,p) \wedge length(p) = [5, mile]]$

Motion Classes

Move	run, fly, drive
Move_External	drive around, pass
Move_Internal	walk around the room
Leave	leave, desert
Reach	arrive, enter, reach
Detach	take off, disconnect, pull away
Hit	land, hit
Follow	follow, chase
Deviate	flee, run from
Stay	remain, stay

IV. Applications & Research Topics

40 mins

Overview

- Space, Time, & Motion Annotation
- Applications
- Open issues & further research topics.

SPACE, TIME & MOTION ANNOTATION

Initial Conceptual Inventory for Spatial Language Annotation

- Locations (regions, spatial objects): Geographic, Geopolitical Places, Functional Locations
- Entities viewed as Spatial Objects
- Paths as Objects: routes, lines, turns, arcs
- Topological relations: *inside*, *connected*, *disconnected*
- Direction and Orientation: *North*, *downstream*
- Time and space measurements: units and quantities for spatial and temporal concepts
- Object properties: intrinsic orientation, dimensionality, size, shape
- Frames of reference: absolute, intrinsic, relative
- Spatial Functions: *behind the building, twenty miles from Boulder*
- Motion: tracking moving objects over time

SpatialML Examples

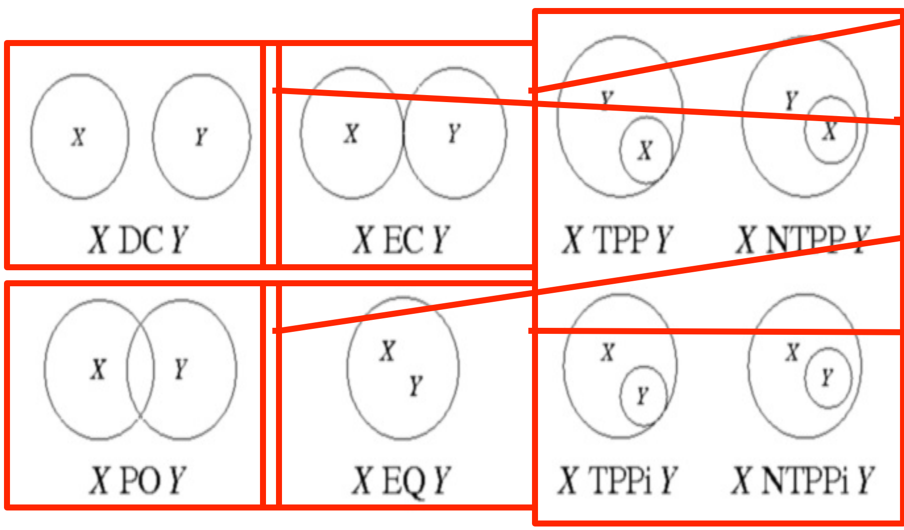
The ISO-Space meeting was held at a [$_{\text{form=NOM, type=FAC}}$ building$_{L1}$] [$_{\text{type=DISTANCE}}$ 50 miles$_{s1}$] [$_{\text{type=DIRECTION}}$ southwest$_{s2}$] of [$_{\text{form=NAM, country=US, latLong=38°53'N 77°02'W}}$ Washington$_{L2}$].

[$_{\text{distance=2, direction=SW, frame=EXTRINSIC, signals=s1 s2}}$ L2 L1 $_{\text{RLINK1}}$]

An [$_{\text{form=NOM}}$ escarpment$_{L1}$] in$_{s2}$ [$_{\text{form=NAM, country=ZA}}$ South Africa$_{L2}$].

[$_{\text{signals=s2}}$ L1 IN L2 $_{\text{LINK1}}$]

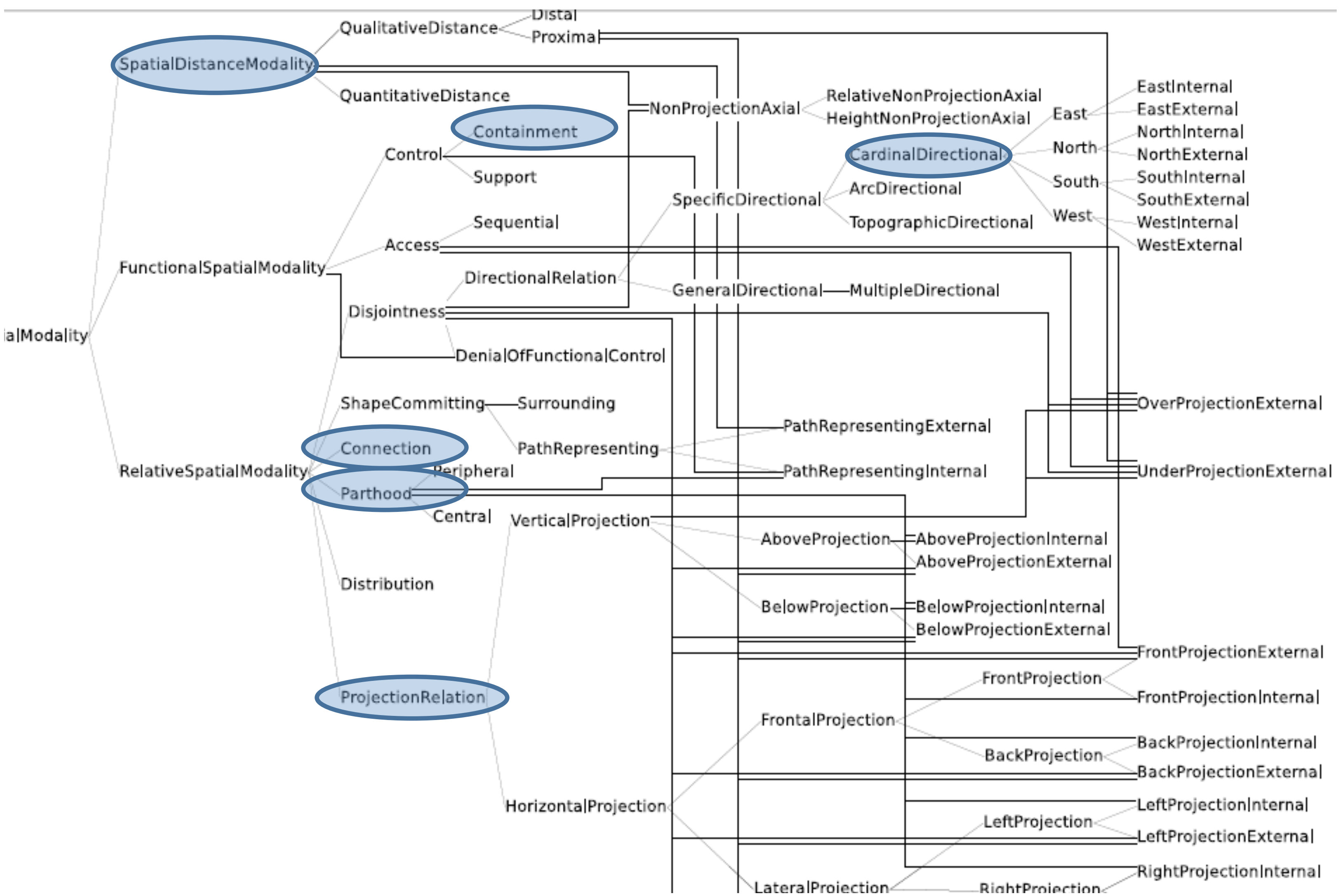
SpatialML & RCC-8



(Randell, Cui and Cohn, 1992)

RCC LinkType	Example
IN (tangential and non-tangential proper parts)	[Paris], [Texas]
EC (external connection)	the border between [Lebanon] and [Israel]
DC (disconnection)	the [well] outside the [house]
PO (partial overlap)	[Russia] and [Asia]
EQ (equality)	[Rochester] and [382044N 0874941W]

Generalized Upper Model (GUM) Ontology



http://www.ontospace.uni-bremen.de/ontology/

SpatialML Representation of Orientation

MOD	Example	GUM Class
BOTTOM, TOP	the bottom of the [well]; the top of the [mountain]	VerticalProjection-Internal
CENTRAL	[central] Thailand; [central] Austrian Alps	CentralParthood; Distribution
E, N, ENE, ESE, NE, NNW, etc.	eastern [province], [North India], the [north] shore of Lake Lugano	CardinalDirectional-Internal
BORDER	[Burmese] border	Connection
NEAR, FAR*	near [Harvard], far from [Bedford]	QualitativeDistanceProximal, QualitativeDistanceDistal

Direction	Example	GUM Class
BEHIND, FRONT	[behind] the house; [in front of] the theater	Horizontal Projection-External
ABOVE, BELOW	[above] the roof, over the clouds; [below] the tree-line, under the clouds	VerticalProjection-External
E, N, S, W, ESE, etc.	[E] of	CardinalDirectional-External
LEFT*, RIGHT*	[to the left of] the sofa; [right]of the church	LateralProjection-External
INSIDE*, OUTSIDE*	[inside] the house; [outside] the school	GeneralDirectional (Containment; DenialofFunctionalControl)
BEFORE*, AFTER*	[before] the house; [after] the church	Sequential

Note that Directions include external relations, and some of the MODs are internal variants of them (e.g., *below the roof* versus *the bottom of the roof*).

***- not yet in SpatialML**

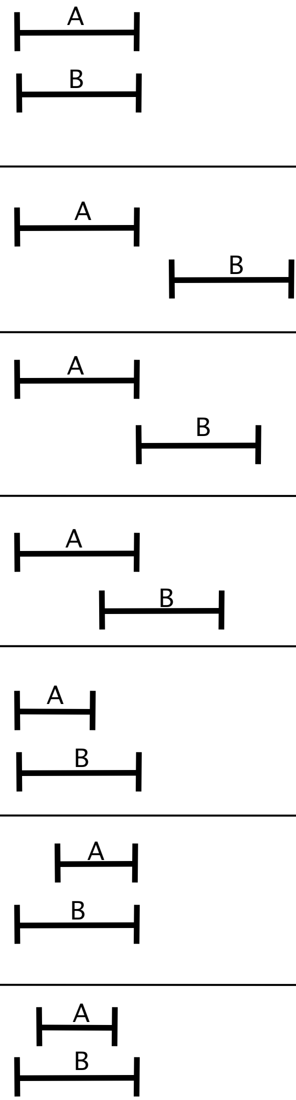
SpatialML with TimeML

He will be biking$_{e1}$ in [$_{\text{form=NAM, country=MX, type=PPL, latLong=16°54'N 92°05'W}}$ Ocosingo$_{L1}$] for [$_{\text{value=P2W, beginPoint=d1, endPoint=d2}}$ two weeks$_{p1}$] from [$_{\text{value=2010-06-07}}$ June 7, 2010$_{d1}$].

[$_{\text{value=2010-06-21, anchorTimeID=p1 d2}}$]

[e1 IS_INCLUDED p1 $_{\text{TLINK1}}$]

TimeML TLINKs mapped to Allen's Interval Relations



TimeML TLINK	Allen relation	Notation
SIMULTANEOUS	A is EQUAL to B	
BEFORE	A is BEFORE B B is AFTER A	<, >
IBEFORE	A MEETS B B is MET by A	m, mi
	A OVERLAPS B B is OVERLAPPED by A	o, oi
STARTS	A STARTS B B is STARTED by A	s, si
ENDS	A FINISHES B B is FINISHED by A	f, fi
INCLUDES	A DURING B B CONTAINS A	d, di

Motion in ISO-Space

John$_{se1}$ [objectID=se1, motion_type=PATH, motion_class=REACH, event_pathID=EVENT_PATH1 arrived$_{m1}$] in$_{s1}$ Boston$_{L1}$.

[signalID=s1, objectID=m1, endID=L1 EVENT_PATH1]

The depression$_{se1}$ was [objectID=se1, motion_type=MANNER, motion_class=MOVE, speed=17mph, event_pathID=EVENT_PATH1 moving$_{m1}$] westward$_{s1}$ at about [17 mph$_{s2}$].

[signalID=s1, objectID=m1, direction=WEST EVENT_PATH1]

John$_{se1}$ is sightseeing$_{e1}$ in$_{s1}$ Boston$_{L1}$.

[eventID=e1, relatedLocationID=L1, signal=s1, type=topological, relation=IN QSLINK1]

The new [tropical depression$_{se1}$] was about [430 miles$_{s1}$] [west of$_{s2}$] the [southernmost Cape Verde Island$_{L1}$], forecasters said.

[eventID=e1, entityID=se1, relatedLocationID=L1, signal=s2, type=relative, relation=WEST QSLINK1]

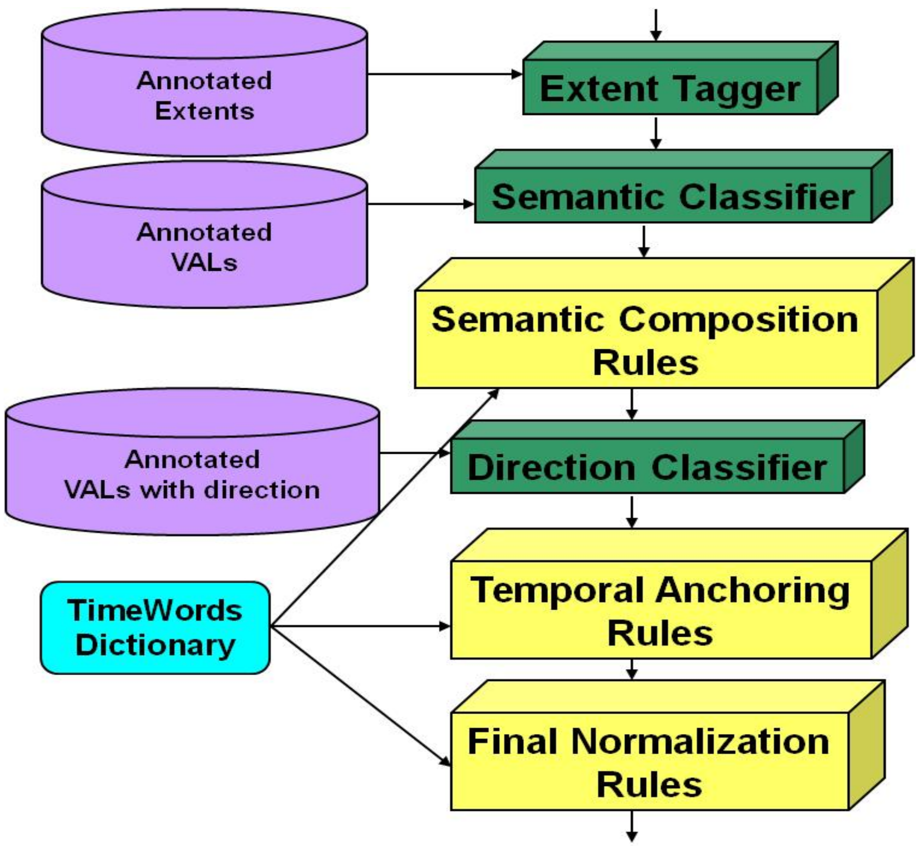
the [beginID=L1, endID=L2 rail road$_{LP1}$] from Boston$_{L1}$ to Maine$_{L2}$.

[traversal=TRAVERSAL1 Take$_{ma1}$] [Route 95$_{LP1}$] to [Exit 21$_{L1}$].

[sourceID=ma1, pathID=LP1, endID=L1 TRAVERSAL1]

Ahn et al. (2007)

Tagging Times



Classifies each word as being part of a time expression or not.

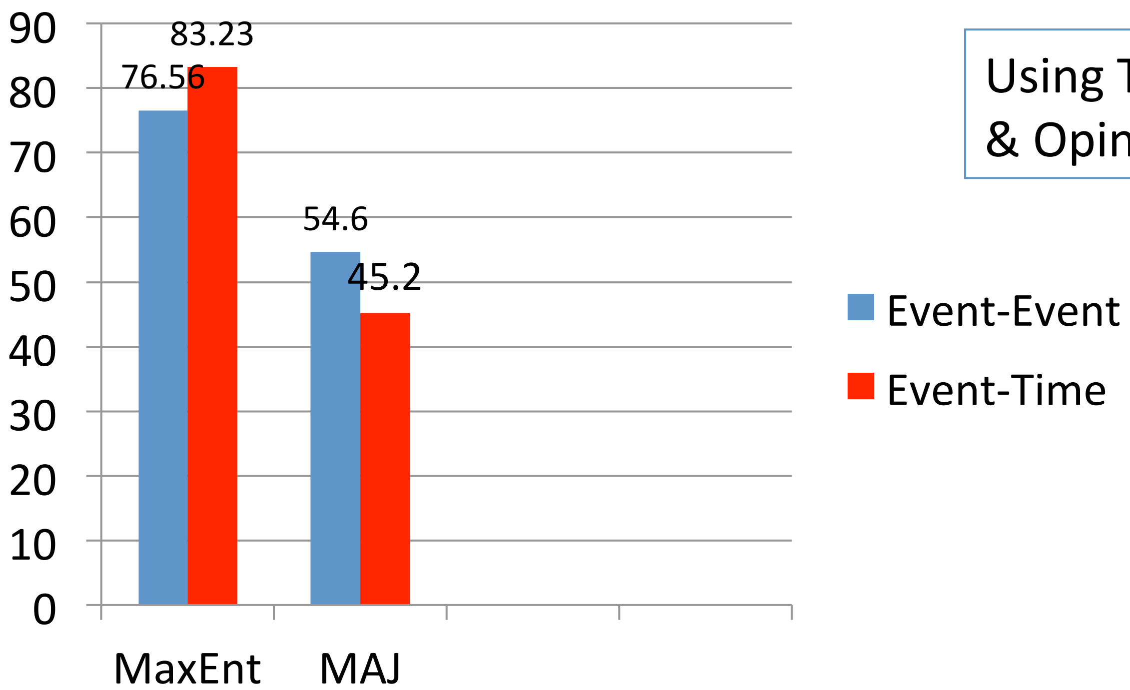
Classifies time expressions into durations, time points, sets of times (e.g, "Thursdays"), and vague expressions, like "several hours" (VAL= "PTX") and "now" (VAL= "PRESENT_REF").

Classifies each time expression's value as "before", "after", or "same" as the reference time.

- Extent tagger is 93.0 F-measure.
- Overall task accuracy is 88.8 F-measure on TERN'2004 test-data.
- Humans: 85.0, 80.0.

Mani et al. (2006, 2007)

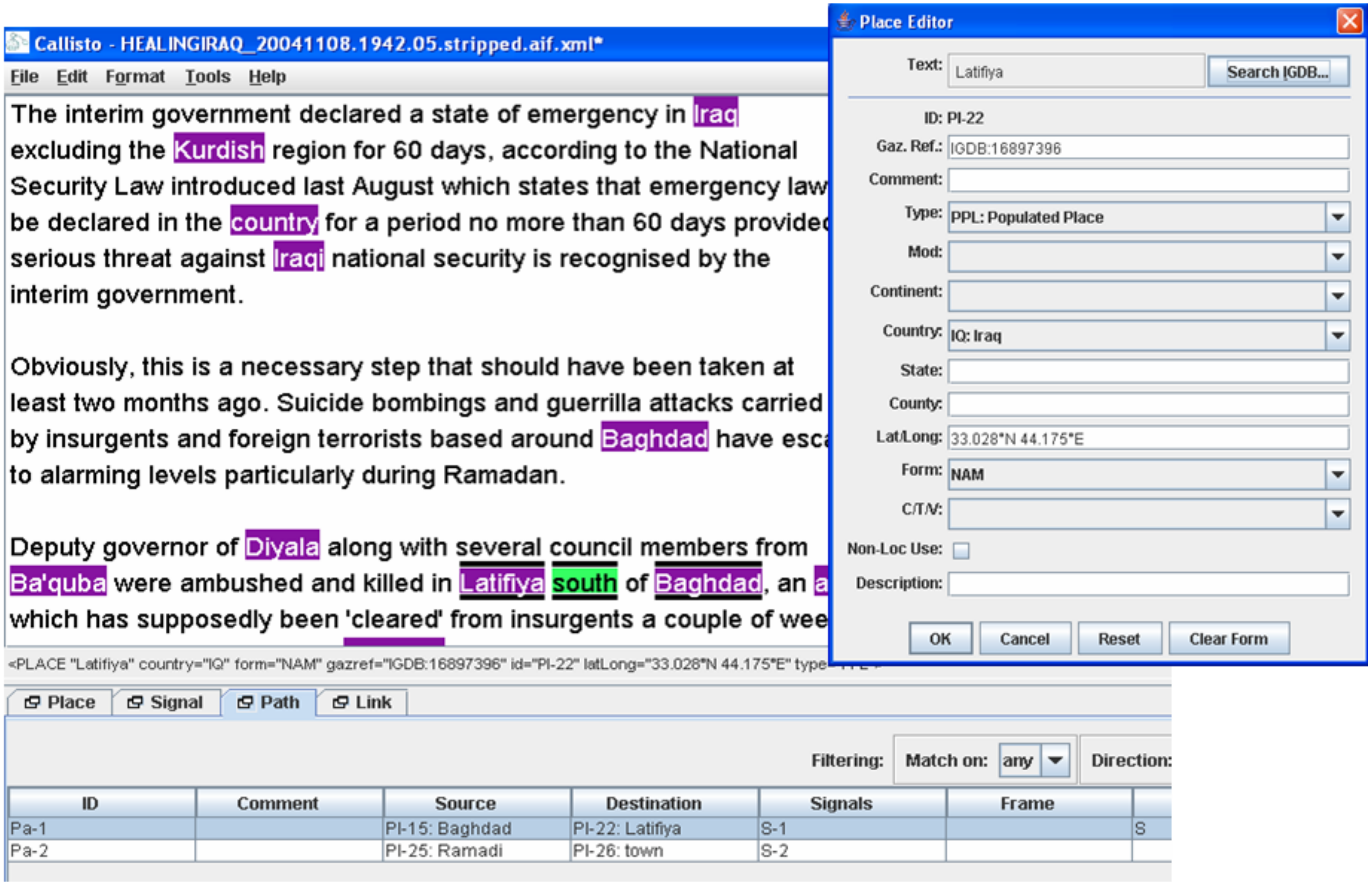
Labeling TLINKs



Using TimeBank
& Opinion Corpus

- These results were obtained by
  1. applying temporal closure to oversample the number of TLINKs (e.g., 5,300 → 13, 985 Event-Event TLINKs),
  2. training and testing on the closed data.
- Document boundaries were ignored.
- Human agreement: TLINKs & labels: 0.55F; TLINK labels: 0.77F

Callisto SpatialML Task



http://callisto.mitre.org

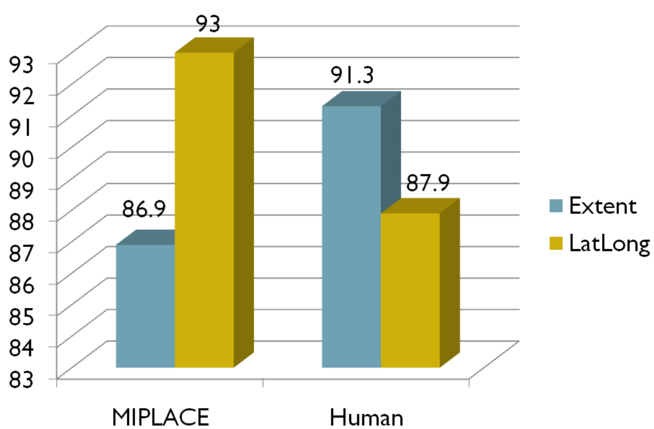
http://sourceforge.net/projects/spatialml/files/latest/download

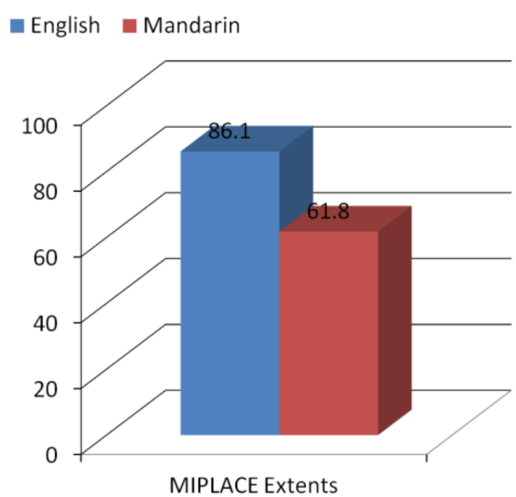
Mani et al. (2010)

Extracting PLACEs

a building 5 miles east of Fengshan

Using ACE Corpus *428 docs, 6338 Places* (news, newsgroup, blogs, broadcast news, broadcast conversation)

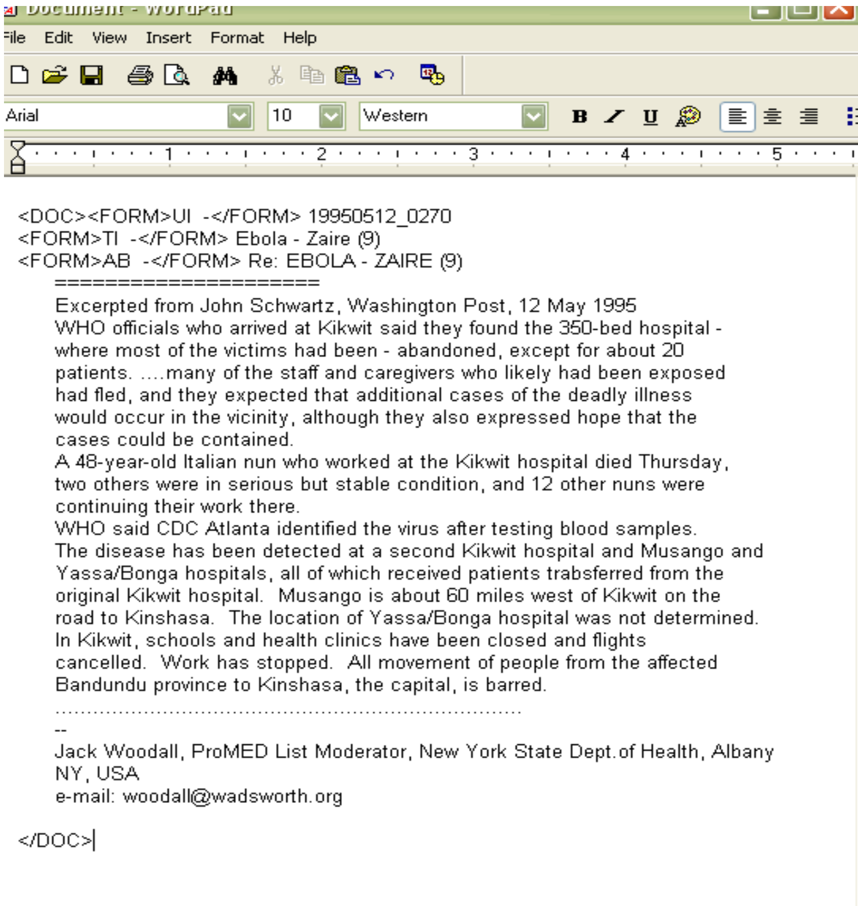




Using ACE Mandarin Corpus without a gazetteer!!

- *298 docs , 4194 Places*

Summarizing PLACEs



Document - WordPad

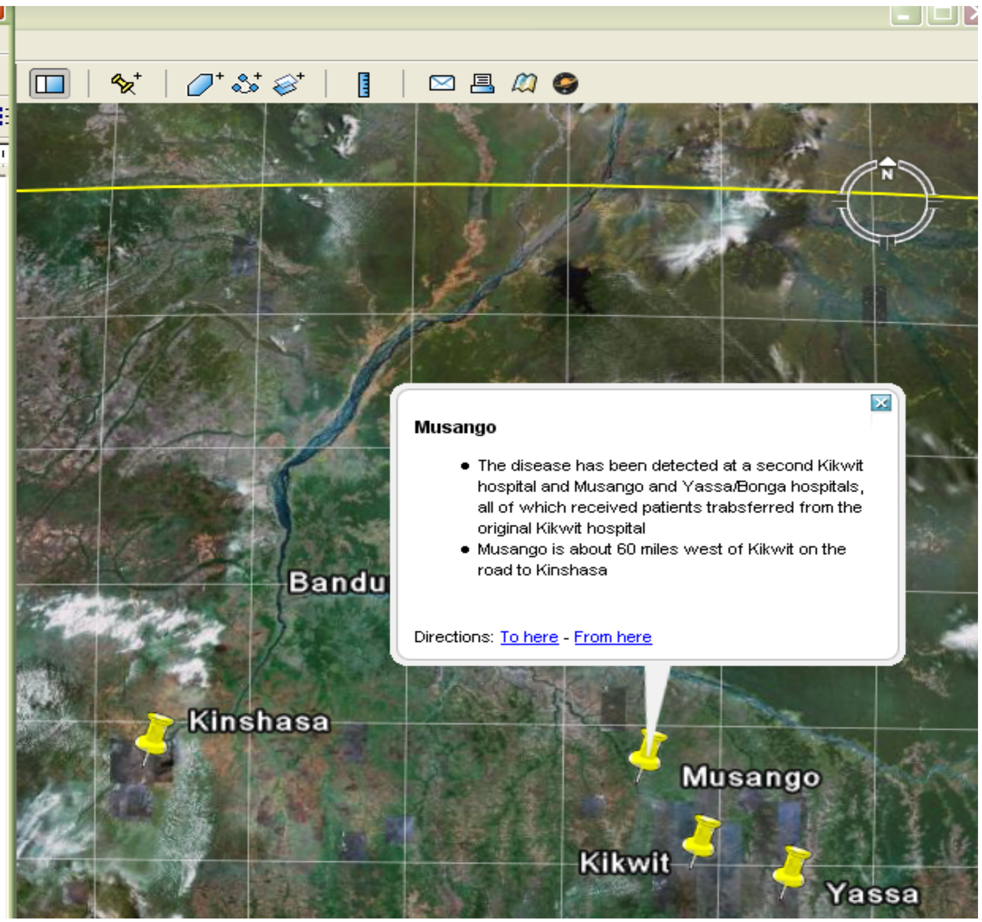
File Edit View Insert Format Help

Arial 10 Western

<DOC><FORM>UI -</FORM> 19950512_0270
<FORM>TI -</FORM> Ebola - Zaire (9)
<FORM>AB -</FORM> Re: EBOLA - ZAIRE (9)
=====================

Excerpted from John Schwartz, Washington Post, 12 May 1995
WHO officials who arrived at Kikwit said they found the 350-bed hospital - where most of the victims had been - abandoned, except for about 20 patients. ....many of the staff and caregivers who likely had been exposed had fled, and they expected that additional cases of the deadly illness would occur in the vicinity, although they also expressed hope that the cases could be contained.
A 48-year-old Italian nun who worked at the Kikwit hospital died Thursday, two others were in serious but stable condition, and 12 other nuns were continuing their work there.
WHO said CDC Atlanta identified the virus after testing blood samples.
The disease has been detected at a second Kikwit hospital and Musango and Yassa/Bonga hospitals, all of which received patients trabsferred from the original Kikwit hospital. Musango is about 60 miles west of Kikwit on the road to Kinshasa. The location of Yassa/Bonga hospital was not determined.
In Kikwit, schools and health clinics have been closed and flights cancelled. Work has stopped. All movement of people from the affected Bandundu province to Kinshasa, the capital, is barred.
....
--
Jack Woodall, ProMED List Moderator, New York State Dept.of Health, Albany NY, USA
e-mail: woodall@wadsworth.org

</DOC>



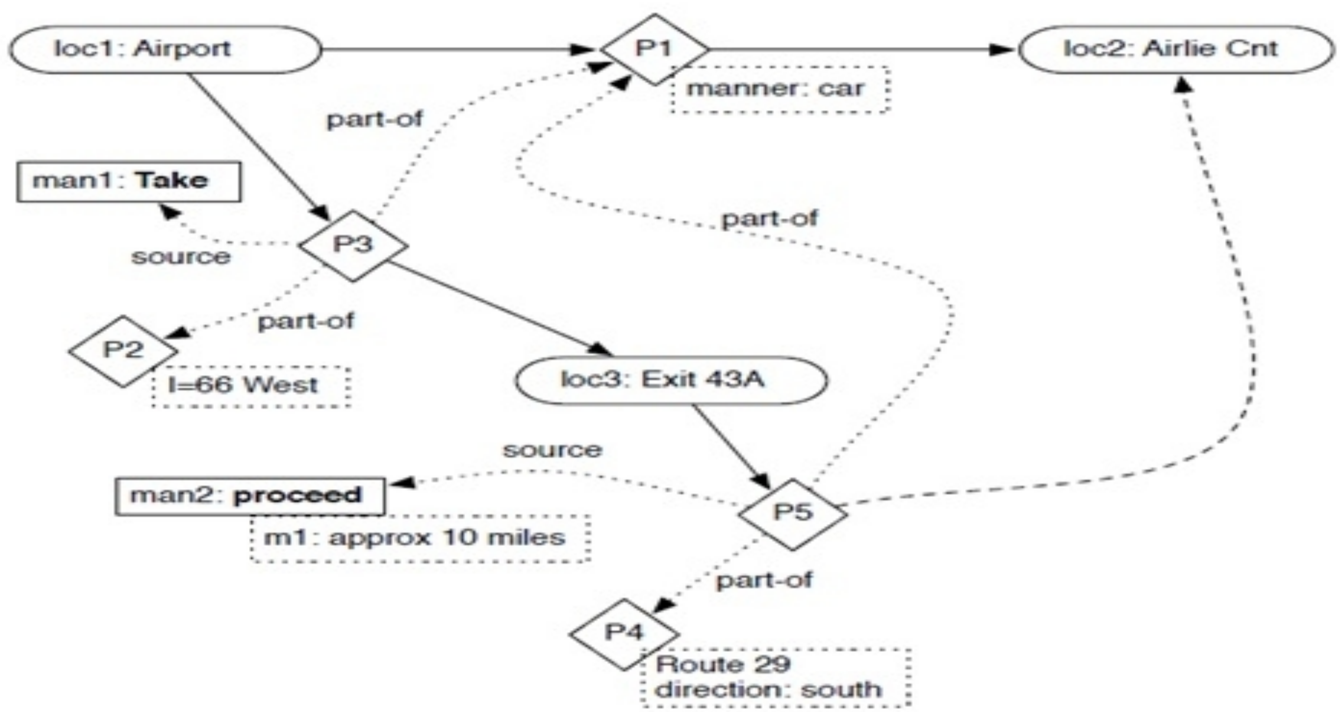
ROUTE NAVIGATION

Applications

- Building a spatial map of objects relative to one another.
- Reconstructing spatial information associated with a sequence of events.
- Determining object location given a verbal description.
- Translating viewer-centric verbal descriptions into other relative descriptions or absolute coordinate descriptions.
- Constructing a route given a route description.
- Constructing a spatial model of an interior or exterior space given a verbal description.
- Integrating spatial descriptions with information from other media.

Route Directions as Maneuvers

Directions from [Dulles Airport $_{loc1}$] to [Airlie Center, VA $_{loc2}$]:
Take [I-66 West $_{p2}$] to [Exit 43A (Gainesville/Warrenton)$_{loc3}$] and proceed South on [Rt. 29$_{p4}$] for approximately 10 miles.



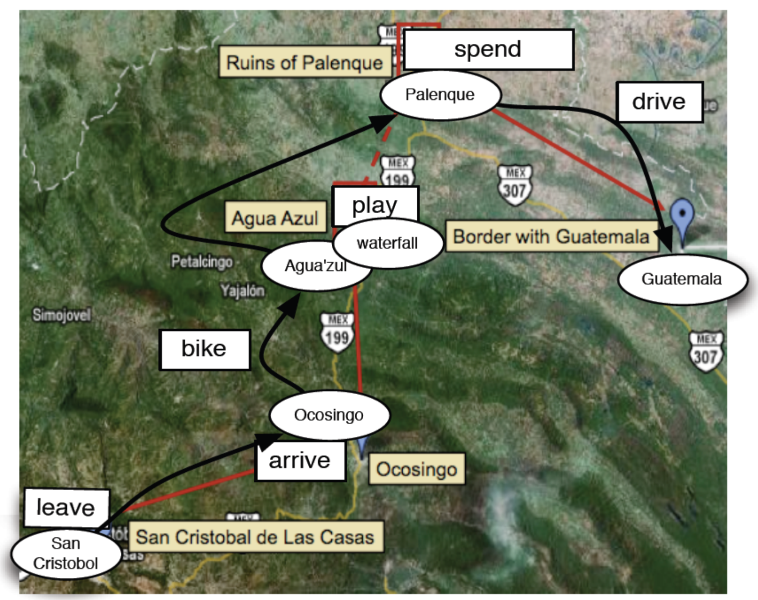
Route Directions as Choremes

- *Take* I-66 West to [Exit 43A (Gainesville/ Warrenton)$_{L1}$] and *proceed* **South** on [Rt. 29$_{p1}$] for approximately 10 miles. *Take* a **right** at the [traffic light$_{L2}$] onto [Colonial Road (Route 605)$_{L3}$]. Colonial Road turns into Airlie Road, *continue* **straight ahead** on [Route 605$_{p2}$]. *Cross* a [one-lane stone bridge$_{L4}$] and *take* an **immediate left** into [Airlie main entrance$_{L5}$].
- L1:WC-S; L2: WC-R; L3: WC-S; L4: WC-S; L5:WC-SL

Mapping Motion from Travel Blogs

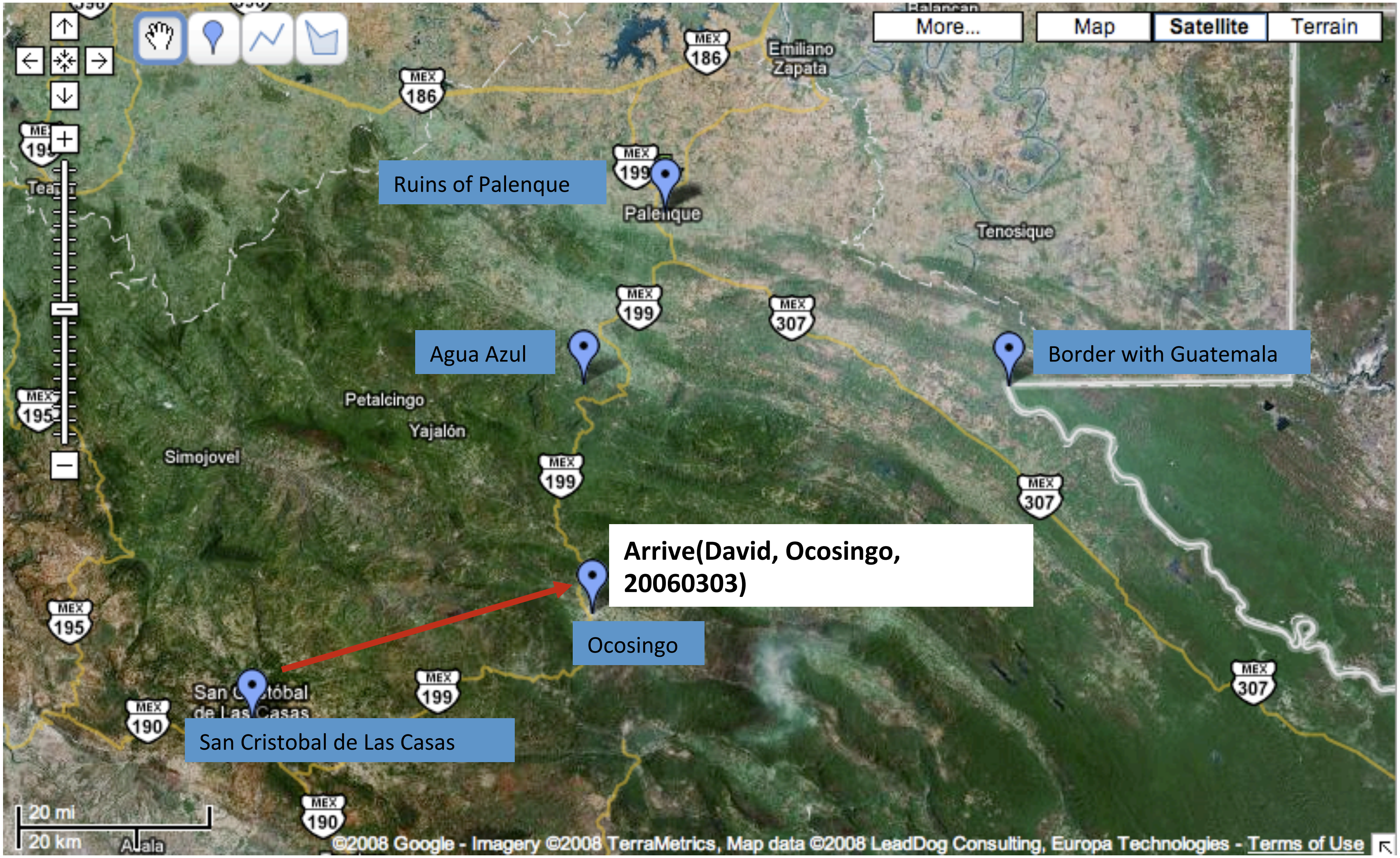
March 7, 2006_{d0}. *Leaving*$_{m1}$ San Cristobal de las $Casas_{L1}$, I_{se1} *biked*$_{m2}$ for one more day_{d1}. I_{se1} *arrived*$_{m3}$ in_{s1} the town of $Ocosingo_{L2}$. The following $morning_{d2}$, I_{se1} *left*$_{m4}$ at $dawn_{t2}$. I_{se1} *biked*$_{m5}$ 30 $miles_{s2}$ to_{s3} the town of Agua $Azul_{L3}$ $where_{s4}$ I_{se1} *played*$_{m6}$ for 4 $hours_{p2}$ in $_{s5}$ $waterfalls_{L4}$. I_{se1} *spent*$_{m7}$ the next day_{d3} at_{s6} the ruins of $Palenque_{L5}$. The following day_{d4}, I_{se1} *drove*$_{m8}$ the 90 $miles_{s7}$ to_{s8} the $border_{L6}$.

Day 1: *Biked* from San Cristobal to Ocosingo.
Day 2: *Biked* from Ocosingo to Agua Azul, 30 miles away.
Played in waterfalls in Agua Azul.
Day 3: *Spent* in Palenque.
Day 4: *Drove* from Palenque to the border, 90 miles away.

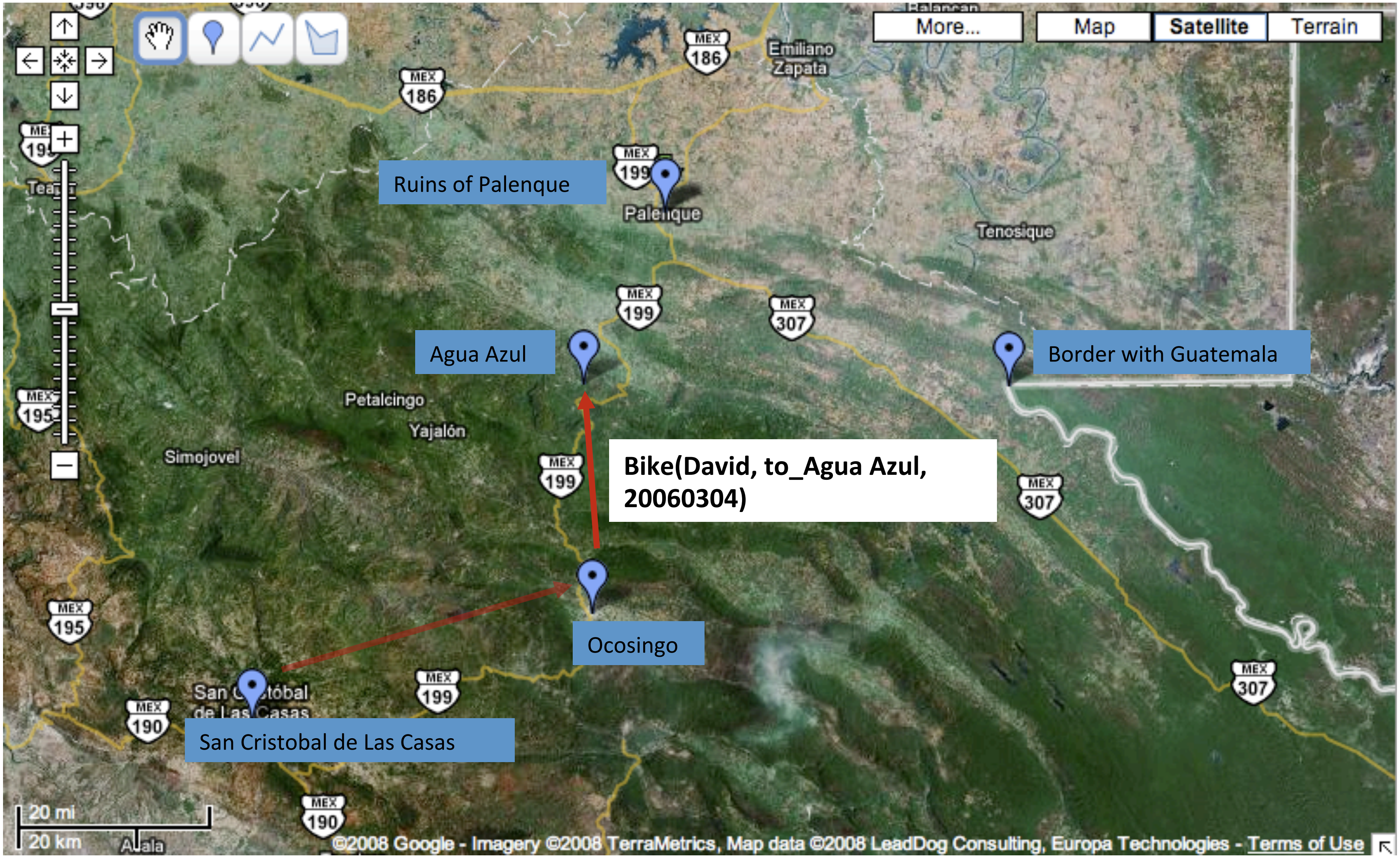


http://www.rideforclimate.com/journals/?cat=3

David left San Cristobal de Las Casas 4 days ago.



David arrived in Ocosingo that day.



The next day, David biked to Agua Azul and played in the waterfalls there for 4 hours.

The next day, David biked to Agua Azul and played in the waterfalls there for 4 hours.

David spent the next day at the ruins of Palenque.

The following day, David drove to the border with Guatemala.

March 3, 2006

David left San Cristobal de Las Casas 4 days ago.

David arrived in Ocosingo that day.

The next day, David biked to Agua Azul and played in the waterfalls there for 4 hours.

David spent the next day at the ruins of Palenque.

The following day, David drove to the border with Guatemala.

March 3, 2006

David left San Cristobal de Las Casas 4 days ago.
David arrived in Ocosingo that day.
The next day, David biked to Agua Azul and played in the waterfalls there for 4 hours.
David spent the next day at the ruins of Palenque.
The following day, David drove to the border with Guatemala.

March 4, 2006

David left San Cristobal de Las Casas 4 days ago.

David arrived in Ocosingo that day.

The next day, David biked to Agua Azul and played in the waterfalls there for 4 hours.

David spent the next day at the ruins of Palenque.

The following day, David drove to the border with Guatemala.

4 hours on
March 4, 2006

David left San Cristobal de Las Casas 4 days ago.

David arrived in Ocosingo that day.

The next day, David biked to Agua Azul and played in the waterfalls there for 4 hours.

David spent the next day at the ruins of Palenque.

The following day, David drove to the border with Guatemala.

March 5, 2006

David left San Cristobal de Las Casas 4 days ago.

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The next day, David biked to Agua Azul and played in the waterfalls there for 4 hours.

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March 6, 2006

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David arrived in Ocosingo that day.

The next day, David biked to Agua Azul and played in the waterfalls there for 4 hours.

David spent the next day at the ruins of Palenque.

The following day, David drove to the border with Guatemala.

QUESTION ANSWERING

Question Answering (1)

- *Question*: In May 1998 Portugal celebrated the 400th anniversary of this explorer's arrival in India*
  - On the 27th of May 1498, Vasco da Gama landed in Kappad Beach
  - ….
- *Answer*: Vasco da Gama

* http://www-03.ibm.com/innovation/us/watson/building-watson/how-watson-works.html

Question Answering (2)

- *Question*: Where did Bill Clinton study before going to Oxford University?*
  - Where did Bill Clinton study?
    - Georgetown University (1964-68)
    - Oxford University (1968-70)
    - Yale Law School (1970-73)
    - ....
  - When did Bill Clinton go to Oxford University?
    - 1968
    - ...
- *Answer:* Georgetown University

* Saquete et al. (2009)

Question Answering Architecture

SCENE RENDERING FROM TEXT

Coyne and Sproat (2001)

WordsEye

- Takes natural language scene-description narratives as input and renders them in animated graphics.
  1. If kicked object is larger than threshold and there is no path, e.g., “John kicked the car”, object is depicted on ground in front of kicker’s foot, with kicker being depicted in ‘kick object’ pose facing object.
  2. When kicked object is small and there is no path or recipient, e.g., “John kicked the football”, kick object pose is used with object placed just above the foot.
     - But in “John kicked the waste-paper basket”, the waste-paper basket is more likely to be on the ground.

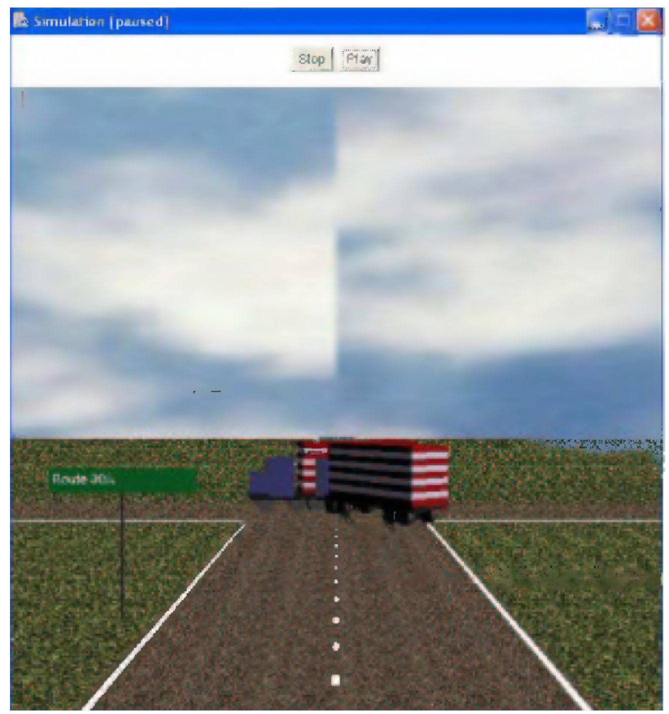
Generated from text: the small red devil is inside the big celadon green say bubble. the say bubble is above the large push button telephone. the say bubble is one inch to the right of the telephone. the telephone is on the desk. the desk is on the humongous parquet floor. a brick wall is behind the desk. it is 10 feet high and 30 feet long.

Akerberg et al. (2003)

Car Sim

- Plans vehicle trajectories based on start and end positions of the vehicles and the spatial configurations of other objects
- Does not fully interpret the text, since just enough information has to be provided to create a pseudo-realistic scenario.
- No systematic treatment of motion verbs, directions, etc.

The bus was traveling north on State Route 30A as it approached the intersection with State Route 7 … Concurrently, an MVFF Construction Company dump truck, towing a utility trailer, was traveling west on State Route 7.



NTSB Example in ISO-Space

- The bus$_{se1}$ was *traveling*$_{m1}$ *north*$_{S1}$ on *State Route 30A*$_{p1}$ as it$_{se1}$ *approached*$_{m2}$ the *intersection*$_{L1}$ with *State Route 7*$_{p2}$ … *Concurrently*$_{S2}$, an MVFF Construction Company *dump truck*$_{se2}$, *towing* $_{m3}$ a utility trailer$_{se3}$, was *traveling*$_{m4}$ *west*$_{S3}$ on *State Route 7*$_{p3}$.

Car Sim Annotation & DITL (1)

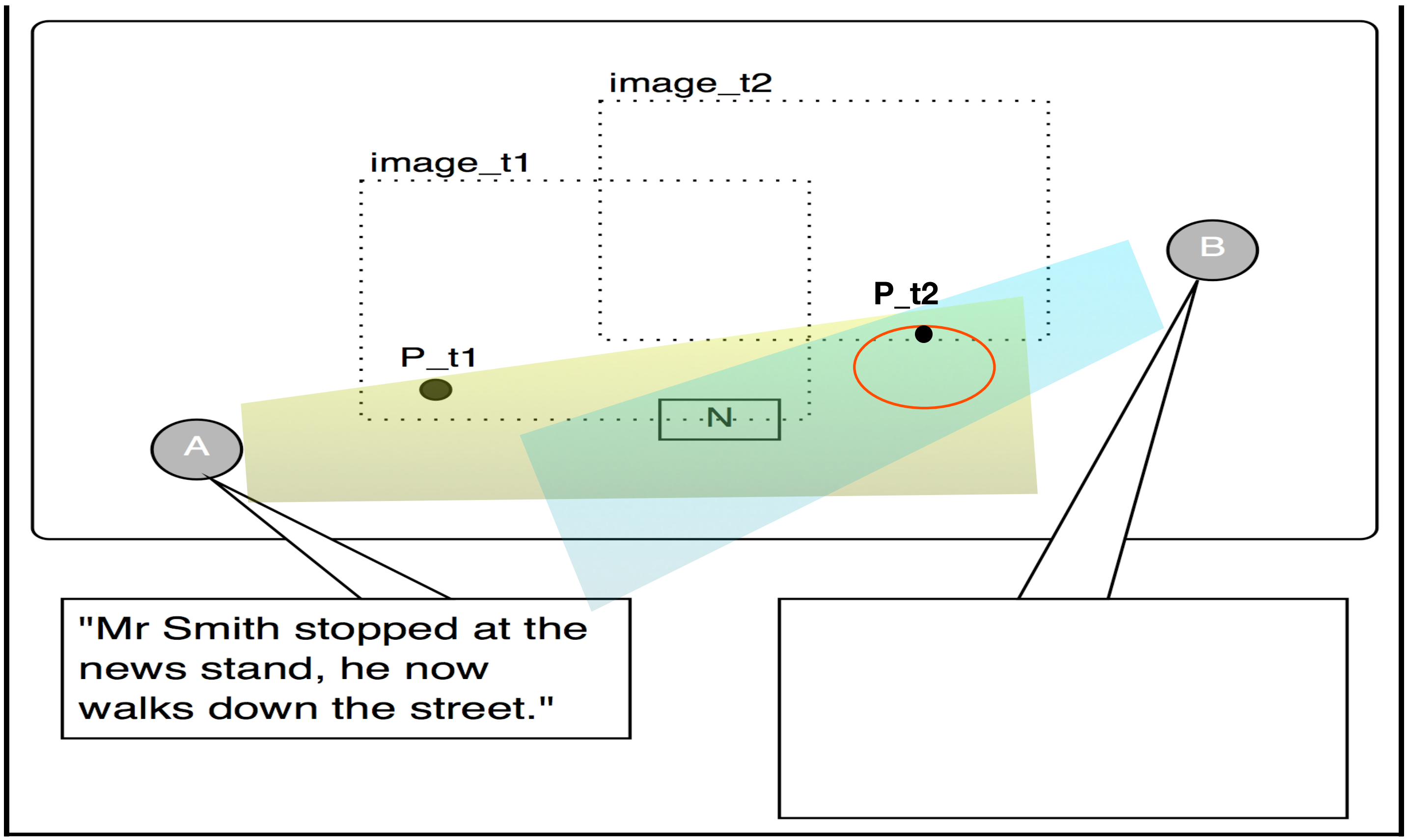
Inference	**Annotation and DITL**
The bus *traveling* is a past directed motion along the path State Route 30A in a northward direction.	[objectID=se1, motion_type=MANNER, motion_class=**MOVE**, event_pathID=EVENT_PATH1 traveling$_{m1}$] [signalID=s1, objectID=m1, direction=NORTH, pathID=p1 EVENT_PATH1] $\boldsymbol{move}_{dir+tr}$(se1) [BEFORE m1 d0 $_{TLINK5}$]
The bus *approaching* is a past directed motion towards the intersection.	[objectID=se1, motion_type=PATH, motion_class=**ATTACH**, event_pathID=EVENT_PATH2 approached$_{m2}$] [objectID=m2, goal=L1 EVENT_PATH2] [BEFORE m2 d0 $_{TLINK5}$] $\boldsymbol{move}_{toward}$(se1, L1)

Car Sim Annotation & DITL (2)

The *towing* is a past being-followed motion of the trailer that is simultaneous with the bus approaching.	[objectID=se3, motion_type=MANNER, motion_class=**FOLLOW**, event_pathID=EVENT_PATH3 towing_{m3}] [objectID=m3 EVENT_PATH3] $\boldsymbol{move}_{follow}$(se3, se2) [BEFORE m3 d0 $_{\text{TLINK5}}$] [SIMULTANEOUS m3 m2]
The truck *traveling* is a past directed motion along the path State Route 7 in a westward direction. The traveling is simultaneous with the bus approaching.	[objectID=se2, motion_type=MANNER, motion_class=**MOVE**, event_pathID=EVENT_PATH4 traveling_{m4}] [signalID=s3, objectID=m1, direction=WEST, pathID=p3 EVENT_PATH4] $\boldsymbol{move}_{dir+tr}$(se2) [BEFORE m4 d0 $_{\text{TLINK5}}$] [SIMULTANEOUS m4 m2]

IMAGE ANNOTATION

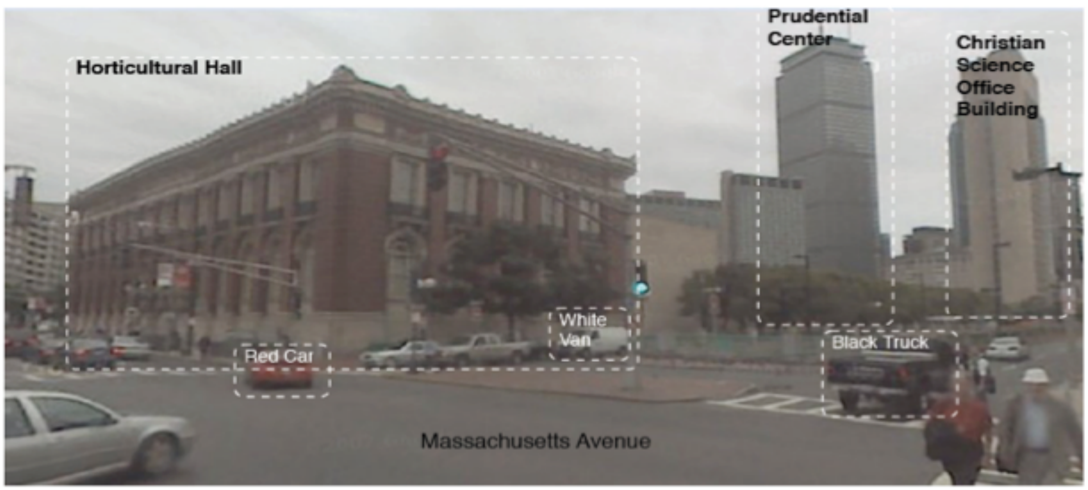
Sample Application



Static Scene Description

- Harder to interpret than motion descriptions
- Prepositions of spatial configuration are more ambiguous than movement verbs
  - on, in, over, under
- Relative spatial descriptions more common
- Projective Prepositional relations are ambiguous

Annotating Images



Horticultural Hall$_{L1}$ is “to the left of” Prudential Center $_{L2}$	[L1 {lf, lp}$_{DCC}$ L2]
the Christian Science Building$_{L3}$ is “to the right of” L2	[L3 {rf, rp}$_{DCC}$ L2]
the white van$_{A1}$ is “in front of” L1	[A1 {sl, sc}$_{DCC}$ L1]
the red car$_{A2}$ is “on” Massachusetts Avenue $_{L4}$	[A2 EC$_{RCC8}$ L4]
the Black Truck$_{A3}$ is “on” Huntingdon Avenue $_{L5}$	[A3 EC$_{RCC8}$ L5]

Frames of reference

- The tree **to the left of** the entrance
- The steps **in front of** me/the entrance

Making a Corpus of Spatially Annotated Linguistic Data

- So far, we have focused on motion and movement verbs
  - Motion Corpus (subcorpus of the current effort)
- General Spatial Configurations
- Model-Annotate-Model-Annotate (MAMA) Strategy
- Amazon Mechanical Turk for quick results

Spatial Preposition HITs

- Data Preparation
  - Begin with the complete set of English prepositions
  - Narrow the focus to those that have the potential to be spatial
  - Reduce to the most frequent 25 potentially spatial prepositions and create a corpus with about ~100 uses of each preposition
- Source of the Corpus Data
  - Open American National Corpus – Berlitz Travel Guides
- Round 1 HIT: Disambiguate the sentences to identify spatial uses

Sample HIT Interface

Identifying Spatial Prepositions

The sentence or sentence fragment below has a preposition hightlighted. Prepositions indicate a relationship between other things in the sentence. We are interested in cases where that relationship has something to do with space. For example, the sentence *The book is* ***on*** *the table* uses the preposition *on* to indicate that there is a spatial relationship between the book and the table. This is very different from *The meeting is* ***on*** *Wednesday* even though the same preposition is used in both sentences.

For the sentence or fragment below, say whether the preposition indicates a spatial relationship or not. The text may contain additional prepositions, but you should only consider the hightlighted one. If you are unsure about your answer, please check the box marked "unsure" and provide your best guess. Thank you!

Today, a majority of people are more or less orthodox Muslims: As you travel **about** Lombok, you will notice many exotic country mosques with their domes and arabesque arcades, as well as the growing numbers of young women who wear robes and headscarves.

- ○ Spatial
- ○ Not Spatial
- ☐ Unsure

Comments:

Submit

Spec Development/Corpus Creation

- Spatial Prepositions, Round 2
  - Identify the figure and the ground within the spatial preposition relation
- Repeat Rounds 1 and 2 for Static Locational Verbs
  - Ex. stand, sit, touch, lean, cover, drape, wear
- Repeat for Motion Verbs
  - Include necessary additional arguments such as path, goal, and course
- Looking ahead
  - Identify additional HIT appropriate tasks for ISO-Space Annotation
  - Consider if Frame of Reference can be examined using Mechanical Turk

Limitations of Spatial Calculi

- It is difficult (impossible?) to distinguish senses of spatial relations in natural language with spatial calculi such as RCC8
  - There is a black stain *on* your shirt sleeve.
  - The clock *on* the wall has the wrong time.
  - The time *on* the clock reads 3:15 pm.
  - Mary put the cup *on* the table.
- Clear sense distinctions but spatial calculi cannot distinguish them

Basic Tags of ISO-Space

- Two tag types:
  - Tags that include text offsets (in most cases) to capture basic elements
    - e.g., locations, motion events
  - Tags that link the basic elements together
    - e.g., qualitative spatial relationships

Location Tags

- Locations come in two varieties:
  - **PLACE** and **PATH**

- **PLACE** Tag
  - Inherited from SpatialML
  - Captures geographic entities like lakes and rivers
  - Captures administrative entities like towns and countries
  - Example
    - A fishing trawler swept away more than a year ago by a tsunami off the east coast of Japan has been spotted floating near British Columbia, Canadian officials said Friday.

Spatial Named Entities

- **SPATIAL_NE** Tag
  - Named entity that is both located in space and participates in an ISO-Space link tag
  - Named entity recognition is not part of ISO-Space
    - Annotators simply mark if a named entity is spatial and add attribute values if needed
  - Example
    - The new tropical depression was about 430 miles (690 kilometers) west of the southernmost Cape Verde Island, forecasters said.
  - Attributes

id	sne1, sne2, sne3, ...
form	NAM or NOM
latLong	a coordinate
mod	a spatially relevant modifier

Events in ISO-Space

- Non-motion **EVENT** Tag
  - An ISO-TimeML event that does not involve a change of location but is directly related to another ISO-Space element
  - Directly inherited from ISO-TimeML
- **MOTION** Tag
  - An ISO- TimeML event that involves a change of location
  - Attributes

id	m1, m2, m3, ...
motion_type	MANNER or PATH
motion_class	MOVE, MOVE_EXTERNAL, MOVE_INTERNAL, LEAVE, REACH, DETACH, HIT, FOLLOW, DEVIATE, STAY

Spatial Signals

- **SPATIAL_SIGNAL** Tag
  - Preposition or other function word or phrase that reveals the relationship between spatial elements
- Cluster Attribute
  - Sense inventory of spatial prepositions
- Semantic Type
  - What kind of relationship the signal triggers
  - e.g., directional --> orientation link
  - e.g., topological --> qualitative spatial link

Spatial Signal Examples

- The book is on$_{s1}$ the table.
  - spatial_signal(s1, cluster="on-1", semantic_type=topological, directional)
- Boston is north of$_{s2}$ New York City.
  - spatial_signal(s2, cluster="north_of-1", semantic_type=directional)
- John is in front of$_{s3}$ the tree.
  - spatial_signal(s3, cluster="in_front_of-1", semantic_type=directional)

Measurements in ISO-Space

- **MEASURE** Tag
  – Captures distances and dimensions
  – Used in measurement links

- Example
- The new tropical depression was about 430 miles$_{me1}$ (690 kilometers$_{me2}$) west of the southernmost Cape Verde Island, forecasters said.
  – measure(me1, value=430, unit=miles)
  – measure(me2, value=690, unit=kilometers)

ISO-Space Relationships

- **QSLINK** – a qualitative spatial relationship between two locations;
- **OLINK** – the orientation of a location or object relative to another;
- **MOVELINK** – the representation of the path of an object in motion;
- **MLINK** – the definition of the distance between two regions or the dimensions of a region.

Qualitative Spatial Links

- Introduced by topological spatial signals
- Uses SpatialML relation types based on RCC8
- Examples
  - [The book$_{sne1}$] is [on$_{s1}$] [the table$_{sne2}$].
    - spatial_signal(s1, cluster="on-1", semantic_type=topological, directional)
    - qslink(qsl1, figure=sne1, ground=sne2, trigger=s1, relType=EC)
  - [The light switch$_{sne3}$] is [on$_{s2}$] [the wall$_{sne4}$].
    - spatial_signal(s1, cluster="on-2", semantic_type=topological, directional)
    - qslink(qsl2, figure=sne3, ground=sne4, trigger=s2, relType=PO)

Orientation Links

- Introduced by directional spatial signals
- Attributes

id	ol1, ol2, ol3, ...
relType	NEAR, ABOVE, BELOW, FRONT, BEHIND, LEFT, RIGHT, NEXT TO, NORTH, ...
figure	identifier of the place, path, spatial named entity, or event that is being related
ground	identifier of the place, path, spatial named entity, or event that is being related to
trigger	identifier of the spatial signal that triggered the link
frame_type	ABSOLUTE, INTRINSIC, RELATIVE
referencePt	cardinal direction, ground entity, viewer entity
projective	TRUE, FALSE

- referencePt and frame_type Interactions

frame_type	referencePt
absolute	cardinal direction
intrinsic	ground ID
relative	viewer ID

OLINK Examples

- [Boston$_{pl1}$] is [north of$_{s1}$] [New York City$_{pl2}$].
  - olink(ol1, figure=pl1, ground=pl2, trigger=s1, relType="NORTH", frame_type=ABSOLUTE, referencePt=NORTH, projective=TRUE)
- [The dog$_{sne1}$] is [in front of$_{s2}$] [the couch$_{sne2}$].
  - olink(ol2, figure=sne1, ground=sne2, trigger=s2, relType="FRONT", frame_type=INTRINSIC, referencePt=sne2, projective=FALSE)
- [The dog$_{sne3}$] is [next to$_{s3}$] [the tree$_{sne4}$].
  - olink(ol3, figure=sne3, ground=sne4, trigger=s3, relType="NEXT TO", frame_type=RELATIVE, referencePt=VIEWER, projective=FALSE)
- [The hill$_{pl3}$] is [above$_{s4}$] [the town$_{pl4}$].
  - olink(ol4, figure=pl3, ground=pl4, trigger=s4, relType="ABOVE", frame_type=INTRINSIC, referencePt=pl4, projective=TRUE)

Metric Links

- Introduced by measures
- Serves two functions:
  - Describe the metric relationship between two spatial objects;
  - Describe the dimensions of a single object
- Attributes

id	ml1, ml2, ml3, ...
figure	identifier of a spatial object
ground	identifier of the related spatial object, if there is one
relType	DISTANCE, LENGTH, WIDTH, HEIGHT, GENERAL_DIMENSION
val	NEAR, FAR, identifier of a measure
endPoint1	identifier of a spatial object at one end of a stative path
endPoint2	identifier of a spatial object at the other end of a stative path

MLINK Examples

- The new [tropical depression$_{sne1}$] was about [430 miles$_{me1}$] ([690 kilometers$_{me2}$]) west of the [southernmost Cape Verde Island$_{pl1}$], forecasters said.
  - mlink(ml1, relType = DISTANCE, figure=sne1, ground=pl1, val=me1)
- [The football field$_{sne2}$] is [100 yards$_{me2}$] long.
  - mlink(ml2, relType = LENGTH, figure=sne2, ground=sne2, val=me2)
- [Times Square$_{pl2}$] stretches from [42nd$_{p1}$] to [47th streets$_{p2}$].
  - mlink(ml3, relType = GENERAL_DIMENSION, figure=pl2, ground=pl2, endPoint1=p1, endPoint2=p2)
- [The office$_{pl3}$] stretches for [25 feet$_{me3}$] from [the bookcase$_{sne3}$] to [the white board$_{sne4}$].
  - mlink(ml4, relType=GENERAL_DIMENSION, figure=pl4, ground=pl3, val=me3, endPoint1=sne3, endPoint2=sne4)
- [The hot dog stand$_{sne5}$] near [Macy's$_{sne6}$].
  - mlink(ml5, relType=GENERAL_DIMENSION, figure=sne5, ground=sne6, val=NEAR)

Location and Spatial_NE Attributes: Dimensionality

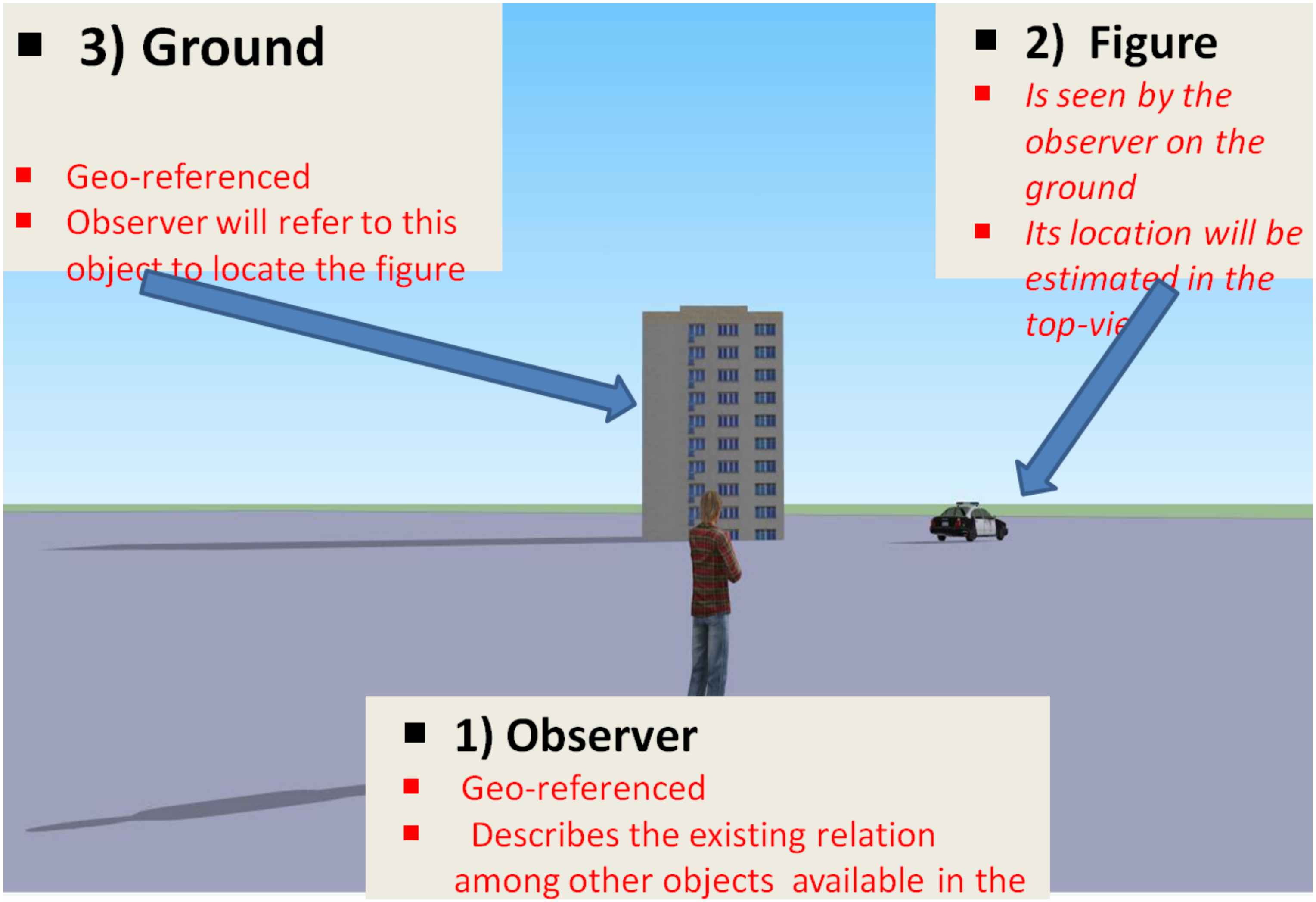
- Point:
  - 0-D - an object that has a position in space, but no length
- Line:
  - 1-D - an object having a length composed of two or more 0-D objects
- Area:
  - 2-D - an object having a length and width bounded by at least three 1-D line segment objects
- Volume:
  - 3-D - an object having a length, width and height/depth bounded by at least four 2-D objects
- Event:
  - 4-D - an object having a temporal dimension/extent

Cf. National Standard for Digital Cartographic Databases

Facings

- Identifiable surfaces of spatial objects:
  - Walls (viewed externally or internally)
  - Ceilings
  - Floors
  - Table top
  - Seat of a chair
- Attributes:
  - Orientation
  - Function

Frames of Reference in Scene



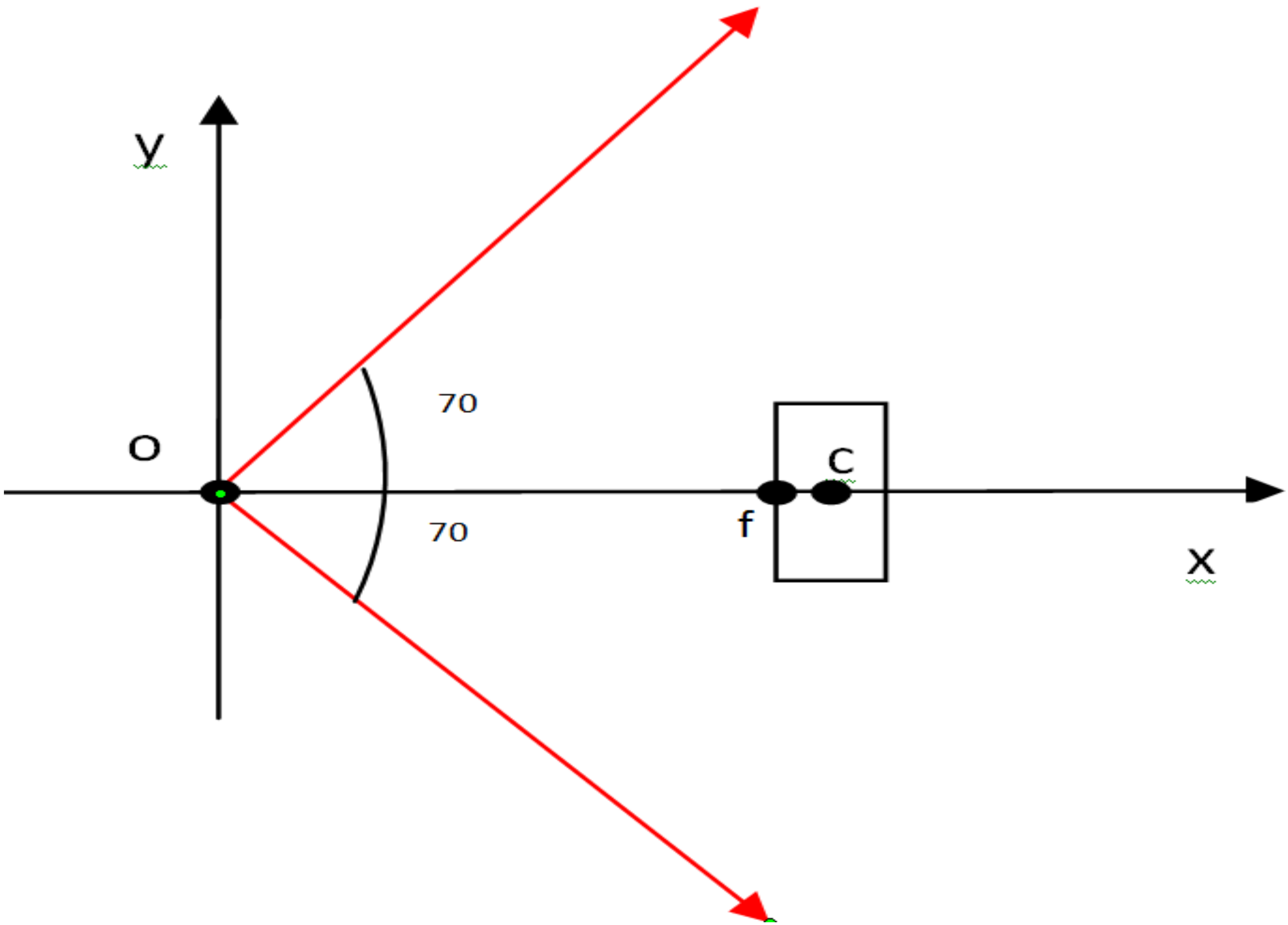
- **3) Ground**
  - Geo-referenced
  - Observer will refer to this object to locate the figure
- **2) Figure**
  - *Is seen by the observer on the ground*
  - *Its location will be estimated in the top-vie…*
- **1) Observer**
  - Geo-referenced
  - Describes the existing relation among other objects available in the scene

Terminology for "Directional relations"

1. The figure is "*leftside of*" the ground object
2. The figure is "*rightside of*" the ground object
3. The figure is "in front *of*" the ground object
4. The figure is "*behind of*" the ground object
5. The figure is "*exactly rightside of*" the ground object
6. The figure is "*exactly in front of*" the ground object
7. The figure is "*exactly behind of*" the ground object
8. The figure is "*beside*" the ground object

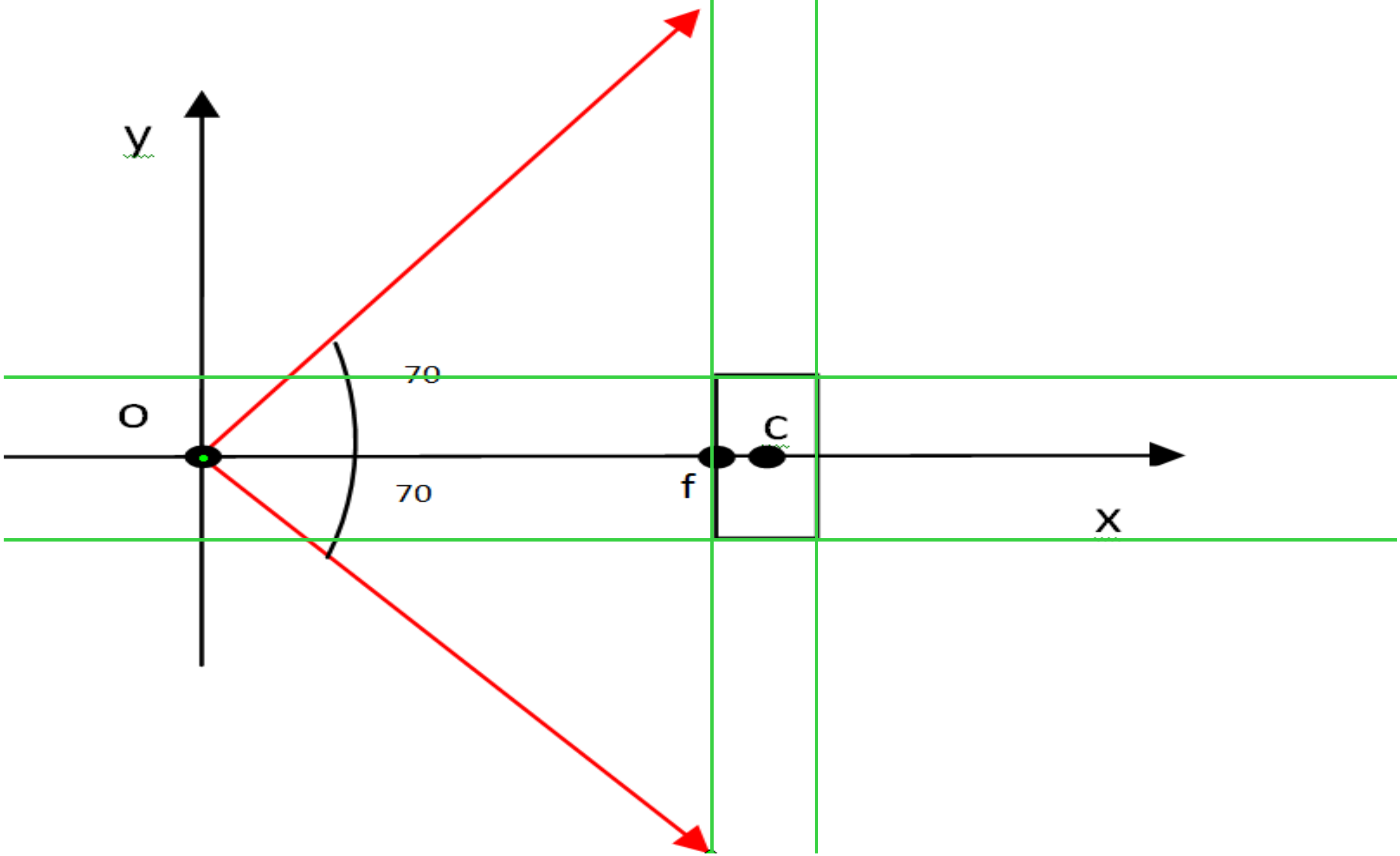
Algorithm:

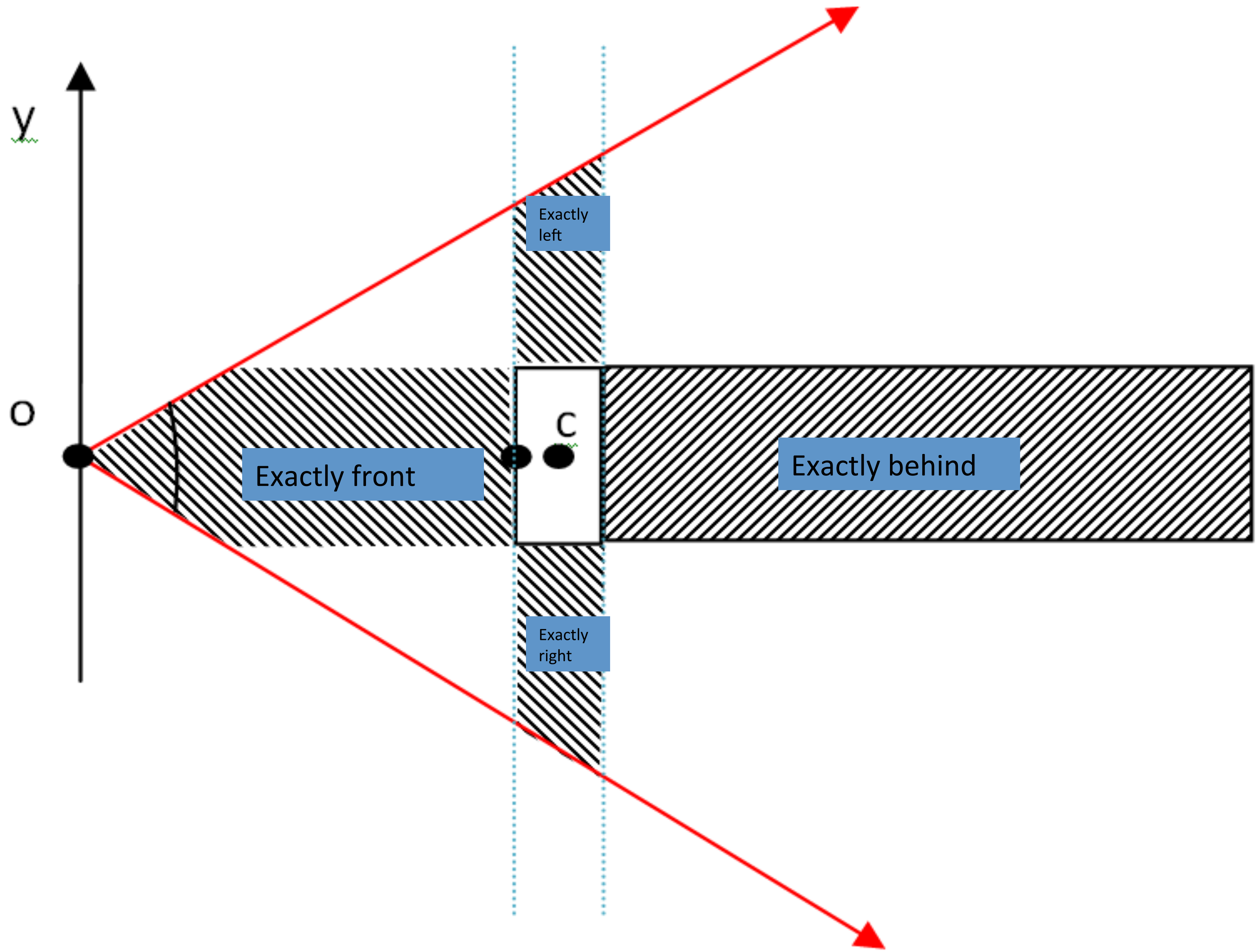
1) Generate the MBR of Ground object and create a subjective coordinate system such as its origin is observer`s position



Algorithm:

2) Find the corresponding regions




y
O
C
Exactly left
Exactly front
Exactly behind
Exactly right

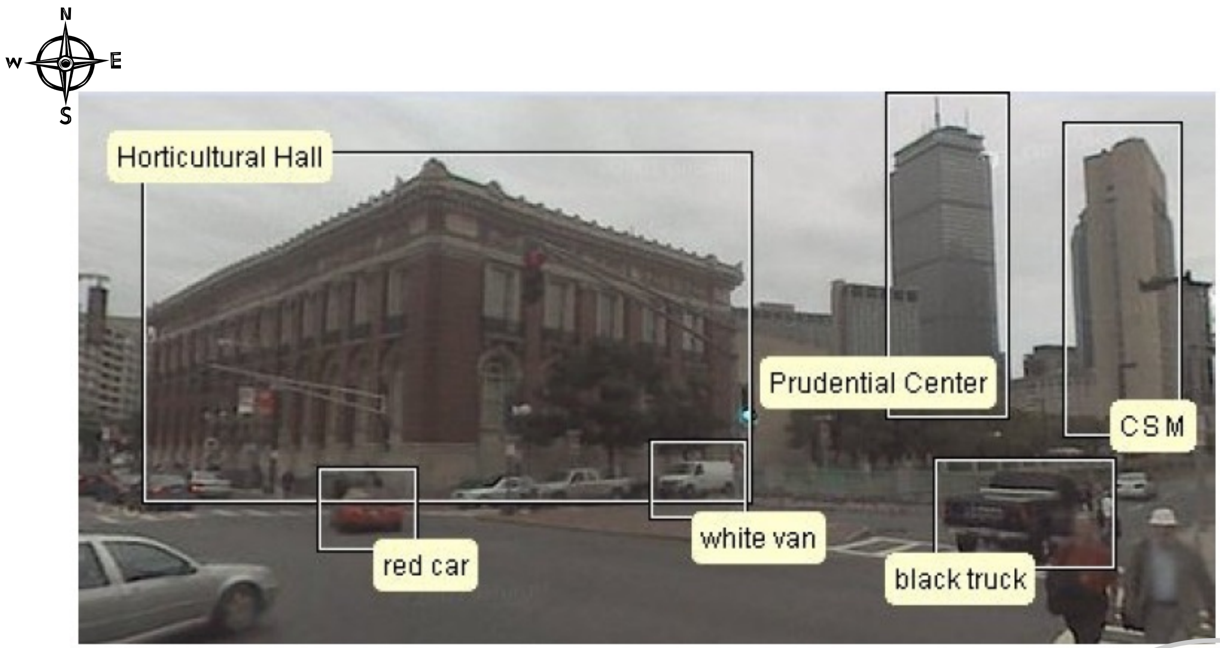
Viewshed Analysis (Stefanidis et al, 2010)

- A viewshed is an area that is visible from a specific location.
- Viewsheds can be calculated using an individual point such as a tower or multiple points.

Methodology

- Collect Google StreetView images
- Annotate with region labels and spatial relations
- Apply viewshed analysis and polygon clipping algorithm
- Evaluate against GPS in gold standard image

Linguistic descriptions of landmark configurations

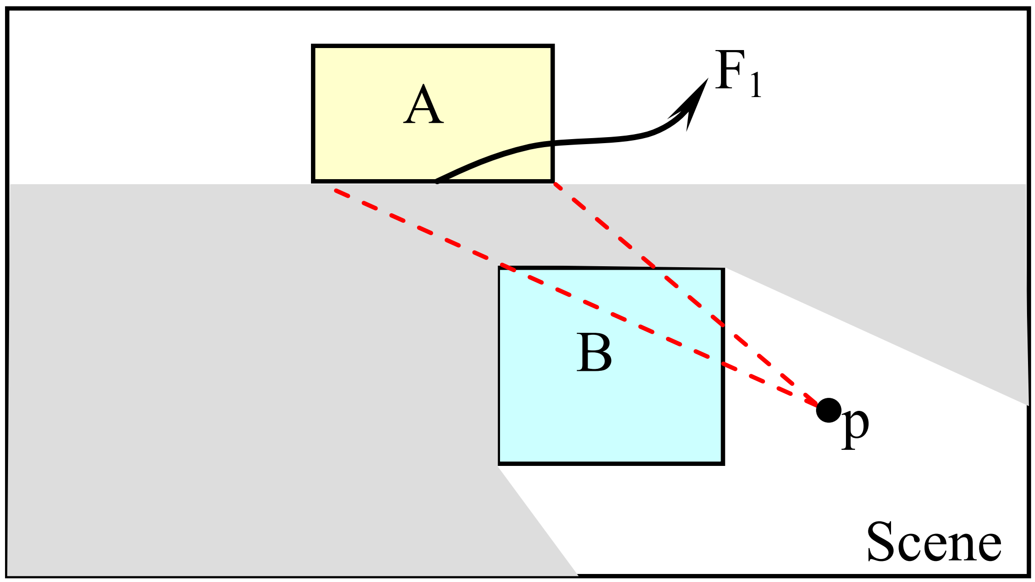


I see the SW and SE sides of Horticultural Hall, and to the right of it I see the SW and SE sides of the Prudential Center, and to the right of it I see the Christian Science Building (CSM).

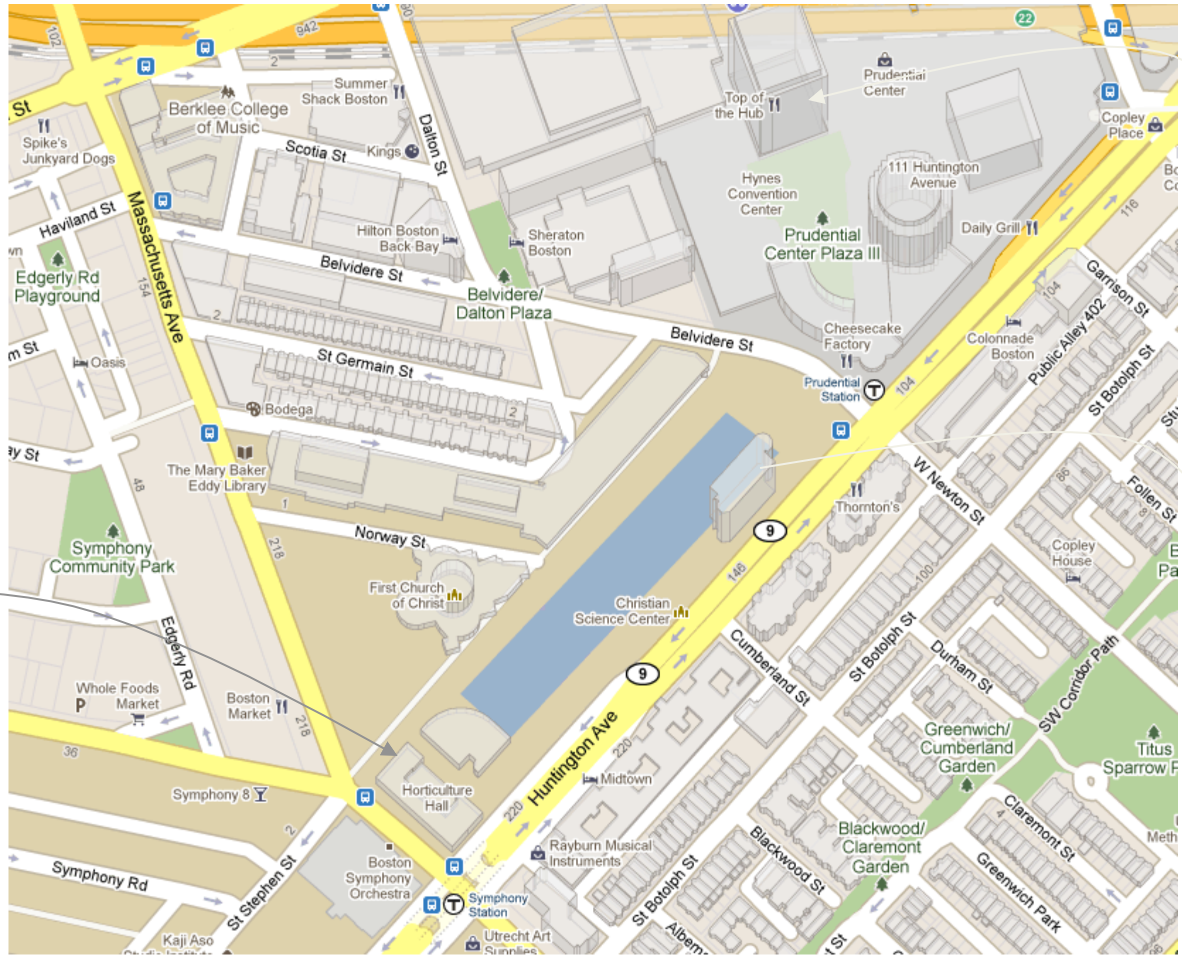
Interpreting landmarks configurations in Language

- "I see the SW and SE sides of Horticultural Hall, and to the right of it I see the SW and SE sides of the Prudential Center, and to the right of it I see the Christian Science Monitor (CSM)"
  - *Explicit reference* to specific landmarks
    - ISO-Space objects
  - *Explicit description* of orientational properties
    - ISO-Space relations (relative position)
  - *Implicit visibility declarations*
    - ISO-Space objects and attributes

2D visibility zone via viewshed analysis

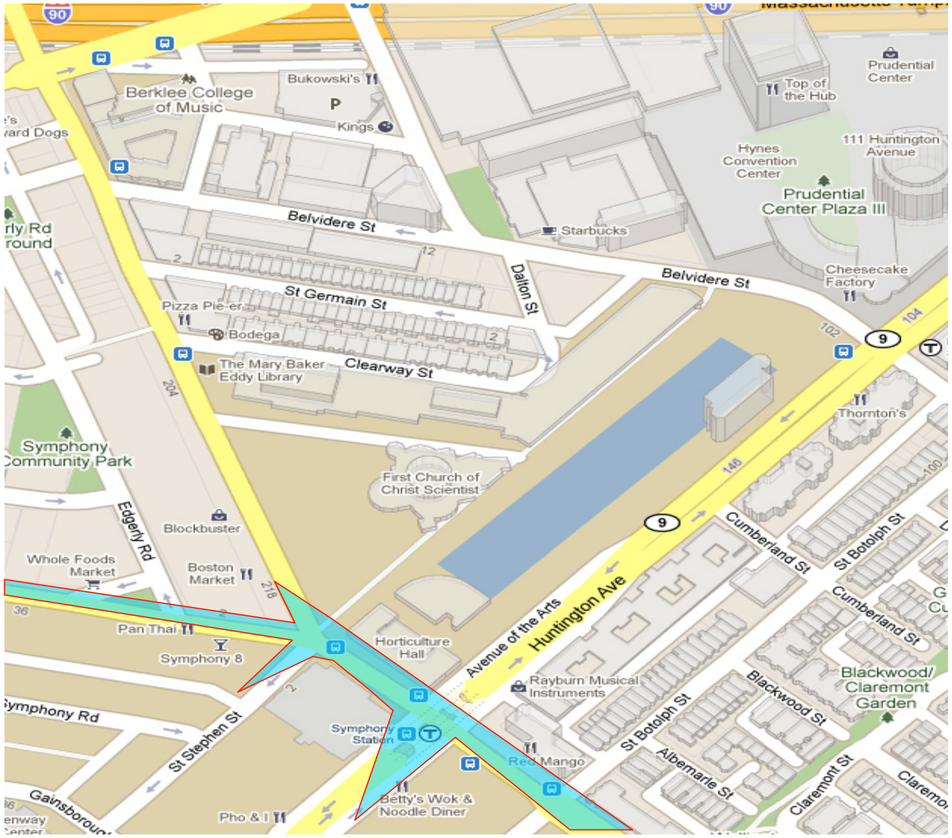


Geolocating the observer

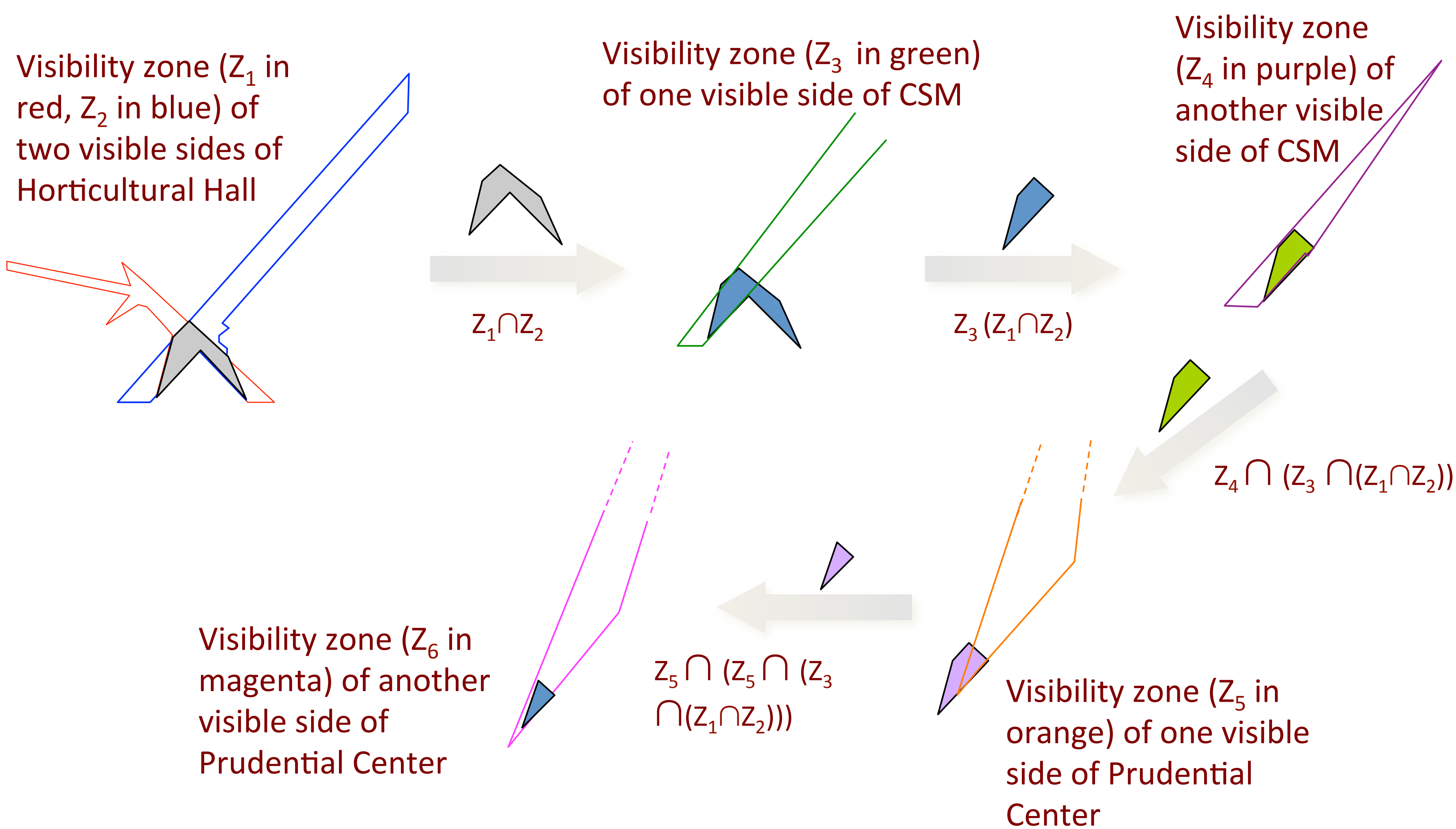


Geolocating the observer (Cont.)

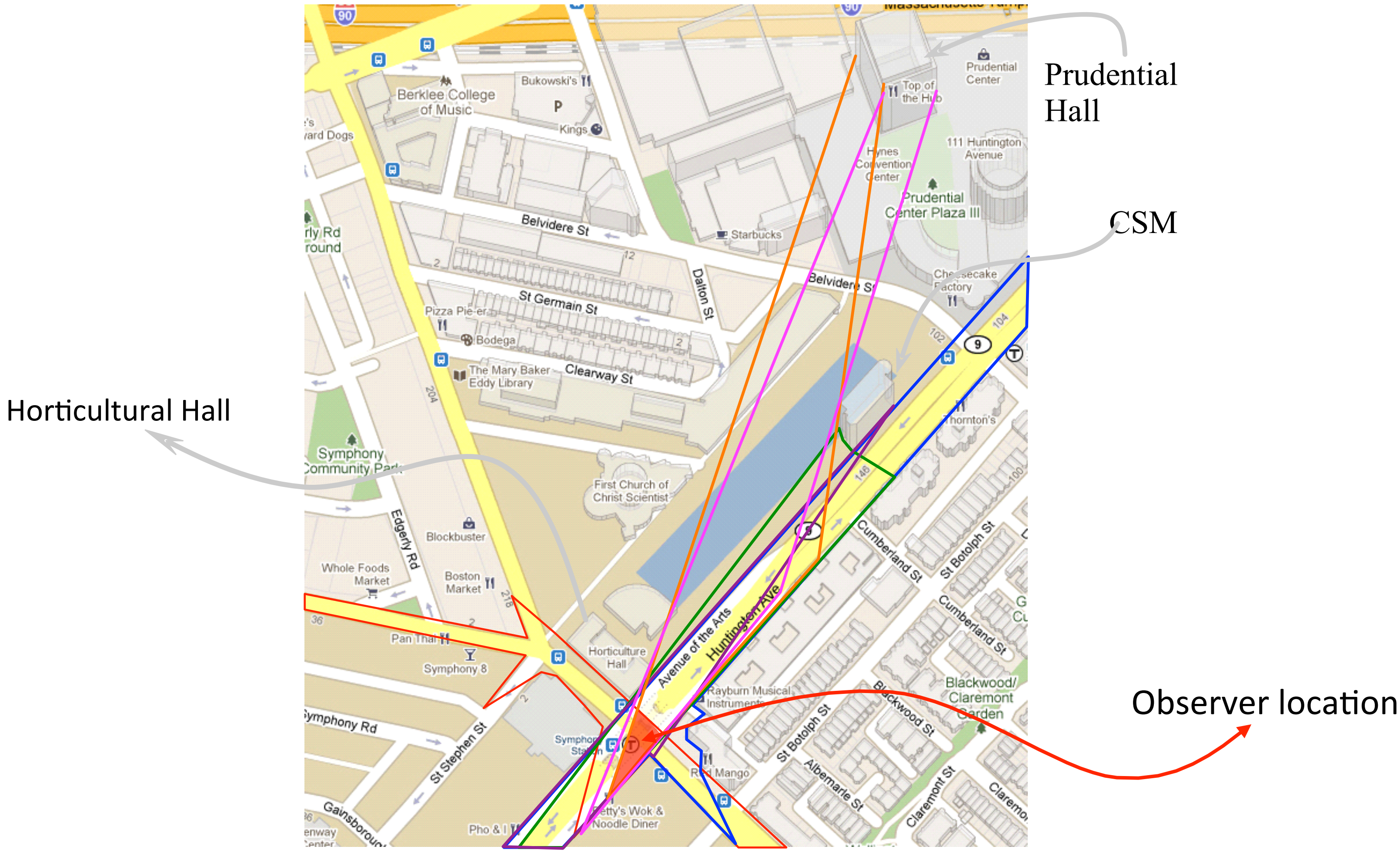
Visibility zone for the SW size of Horticultural Hall



Geolocating the observer (Cont.)



Geolocating the observer (Cont.)



Links

- TARSQI TimeML tagger: http://timeml.org/site/tarsqi/toolkit/download.html
- MIPLACE SpatialML Tagger: http://sourceforge.net/projects/spatialml/files/MIPLACE-release-v1.0b.tar.gz/download
- ACE Corpora:
  - http://www.ldc.upenn.edu/Catalog/catalogEntry.jsp?catalogId=LDC2011T02
  - http://www.ldc.upenn.edu/Catalog/catalogEntry.jsp?catalogId=LDC2010T09

Future Research

- Fictive motion (Talmy 2000)
  - *The islands run between the Atlantic Ocean and the Caribbean Sea*
  - *There is a Civic Trust plaque where a medieval gate used to stop people going into the Park of Leeds.*
  - *This walk begins at Leeds Bridge which crosses the river Aire.*
- Spatial entities
  - 3D, Qualitative size, Qualitative shape
- Integrating Reasoning and Extraction
  - Further integration of qualitative approaches & DITL with NL tagging
  - Global reasoning
- Trainability
  - Using unsupervised & weakly-supervised approaches, transfer learning, & crowdsourcing.