"She had the marvelous sensation of being a part of a vaster world and moving with it because of moving in rhythm with another being. The joy of this was so intense that when she saw him approaching she ran towards him wildly, joyously. Coming near him like a ballet dancer she took a leap towards him, and he, frightened by her vehemence and fearing that she would crash against him, instinctively became absolutely rigid, and she felt herself embracing a statue. Without hurt to her body, but with immeasurable hurt to her feelings."

-Anais Nin, *Stella*

Embodied Models of Language Learning and Use

Session 3: Simulation-based language understanding

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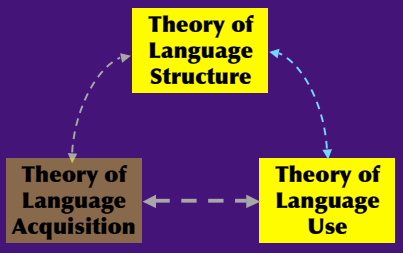


Simulation-based language understanding

Session 3 outline

1. (Re-)introduction: simulation
2. Embodied Construction Grammar
3. Understanding metaphorical language

1. Embodiment and Simulation

"What is an idea?
It is an image that paints itself in my brain."
— *Voltaire*

Embodied inferences

The scientist walked into the wall.

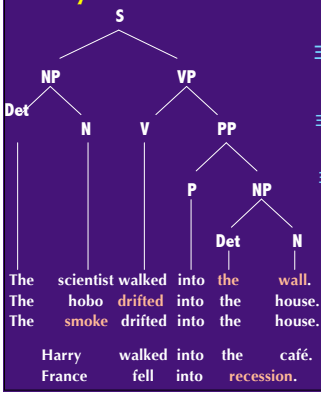
The hobo drifted into the house.

The smoke drifted into the house.

Metaphorical inference

- Economic metaphors
  - France **fell** into recession. Germany **pulled** it **out**.
  - The economy is **moving** at the **pace of a Clinton jog**.
  - The Indian Government is **stumbling** in implementing its liberalization plan.

Syntax and semantics (standard)



$\exists e,y$: CAFE(y) ∧ WALK(e,Harry) ∧ INTO(e,y)

$\exists x, y$: RECESSION(y) ∧ WALK(e,France) ∧ INTO(e,y)

$\exists e,x,y$: SCIENTIST(x) ∧ WALL(y) ∧ WALK(e,x) ∧ INTO(e,y)

Truth-conditional semantics

- Meaning is an abstract symbol system
- Words map onto parts of logical statements
- Verbs map onto predicates
- Nouns identify arguments of the predicates
- Meaning of a sentence is a function of the possible worlds in which it is true.

Embodied semantics says: this is inadequate.

Embodied Semantics says:

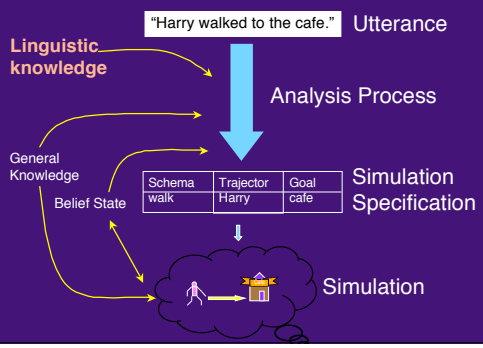
- Meaning is directly related to experience
- Language gains its meaning via the experiences language users have in the world
- The meaning of a prototypical verb is the neural trace of an action
- The meaning of a prototypical noun is the memory of a category of objects
- The meaning of a sentence is the simulation of an event
- cf. (Landauer, Foltz, Laham 1998); (Boroditsky, Ramscar, Frank 2001)

Simulation hypothesis

We understand utterances by **mentally simulating their content**.

- Simulation exploits some of the **same neural structures** activated during performance, perception, imagining, memory…
- Linguistic structure **parameterizes** the simulation.
  - Language gives us enough information to simulate

Language understanding as simulative inference



Suggestive evidence

- Mirror system raises possibility of **integrated, multi-modal representation** of actions, along with objects and locations
- **Global economy: a neural Occam's razor:** exploit existing sensory-motor systems for language understanding

Mirror neurons for language (1)

- **Mirror neurons for specific effectors activated during passive listening:**
  - Sentences describing mouth/leg/hand motions activates corresponding part of pre-motor cortex (Tettamanti et al. 2002)
  - Verbs associated with particular effectors activates corresponding areas of motor cortex (Pulvermuller et al. 2001, Hauk et al. 2004)

Mirror neurons for language (2)

- **Premotor areas that are activated most for observation of hand/mouth actions are also most activated for literal phrases pertaining to the hand/mouth (Aziz-Zadeh)**
  - e.g. "grasp the cup" = hand motor area
  - Left hemisphere specialization
- **Under way: metaphor, perceptual**
  - "I see what you mean" = visual area
  - "flew past me" = visual motion areas
  - "hear the music" = auditory areas

Psycholinguistic evidence

- **Embodied language impairs action/perception**
  - Sentences with **visual components** to their meaning can interfere with performance of visual tasks (Richardson et al. 2003)
  - Sentences describing motion can interfere with performance of **incompatible motor actions** (Glenberg and Kashak 2002)
  - Sentences describing **incompatible visual imagery** impedes decision task (Zwaan et al. 2002)
- **Simulation effects from fictive motion sentences**
  - Fictive motion sentences describing paths that require **longer time**, span a **greater distance**, or involve **more obstacles** impede decision task (Matlock 2000, Matlock et al. 2003)

Implementations

- Embodied representations the norm in robotics! (Brooks, Pfeiffer, Steels, etc.)
- Computational representations for lexical semantics have been developed for:
  - **Spatial relations** (Regier 1996)
  - **Actions** (Bailey 1997, Narayanan 1997, Siskind 2001)
  - **Objects / attributes** (Roy 1998)
- Connectionist reductions (Shastri et al., 1998)
- Metaphor understanding system based on simulation (Narayanan 1997)

Toward a computational account

- **Embodied representations that can be simulated**
  - Previous computational models, word learning
- **Grammatical formalism for linking the forms of language with embodied representations**
  - Cognitive linguistics
  - Construction Grammar
- **Detailed descriptions of the processes involved in language analysis / simulation**

2. Embodied Construction Grammar

"It is not enough to say that the mind is embodied; one must say how."

— Damasio

What is grammar?

- "Syntactic investigation of a given language has as its goal the construction of a grammar that can be viewed as a device of some sort for producing the sentences of the language under analysis." (Chomsky 1957)
- Inadequate notion of grammar
  - **Meaning-free**: syntax separate from meaning, function and processing; unanalyzable symbolic units
  - **Inflexible**: strict word order, strictly hierarchical, strictly compositional

Who's up to the task?

- **Most theories of language are not explicitly and systematically tied to action and perception**
- **Promising exceptions**
  - Cognitive Grammar / cognitive linguistics
  - Construction Grammar
  - Typically criticized for being informal / vague
- **We borrow liberally from both and formalize.**

Cognitive Linguistics

"Language is an integral part of cognition which reflects the interaction of cultural, psychological, communicative, and functional considerations, and which can only be understood in the context of a realistic view of conceptualization and mental processing."

International Cognitive Linguistics Association website (http://www.cognitivelinguistics.org/aims.shtml)

Ideas from Cognitive Linguistics

- **Radial categories / prototype effects** *(Rosch 1973, 1978; Lakoff 1985)*
  - mother: birth / adoptive / surrogate / genetic, …
- **Profiling** *(Langacker 1989, 1991; cf. Fillmore XX)*
  - *hypotenuse, buy/sell* (Commercial Event frame)
- **Metaphor and metonymy** *(Lakoff & Johnson 1980)*
  - ARGUMENT IS WAR, MORE IS UP
  - The ham sandwich wants his check. / All hands on deck.
- **Mental spaces** *(Fauconnier 1994)*
  - The girl with blue eyes in the painting really has green eyes.
- **Conceptual blending** *(Fauconnier & Turner 2002, inter alia)*
  - *workaholic, information highway, fake guns*
  - "Does the name Pavlov ring a bell?" (from a talk on 'dognition'!)

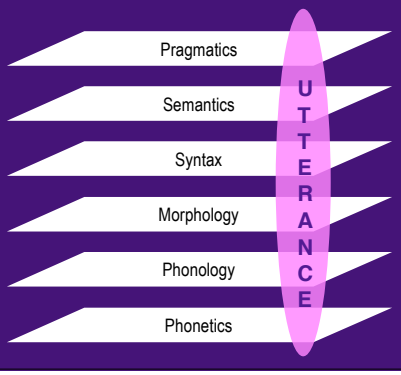
Key borrowed ideas

- **Conceptual structures are embodied.**
  - **Meaning** is **conceptualization** (part of larger cognitive system).
  - **Concepts are grounded in human experience** as physical, psychological and social beings in the world.

  (Lakoff 1987, 1985; Langacker 1991, 1987)
- **Basic symbolic unit at all levels is a form-meaning pair, or construction.**
  - Syntax is not independent of semantics.
  - Phrasal/clausal constructions can contribute meaning independently of constituents.

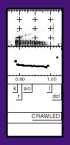
  (Fillmore 1988, Kay & Fillmore 1999, Lakoff 1987, Goldberg 1995)

Traditional levels of analysis



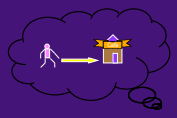
Form-meaning mappings for language

Linguistic knowledge consists of **form-meaning mappings**:



Form
- phonological cues
- word order
- intonation
- inflection

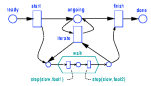
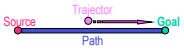
Meaning
- event structure
- sensorimotor control
- attention/perspective
- social goals...



Construction Grammar

A construction is a form-meaning pair whose properties may not be strictly predictable from other constructions.

(Construction Grammar, Goldberg 1995)

Form	Meaning
block	
walk	
to	

Constructions as maps between relations

Complex constructions are mappings between *relations* in form and *relations* in meaning.

Form		Meaning
Mover + *Motion* before(*Mover*, *Motion*)	⟺	*MotionEvent* mover(*Motion*, *Mover*)
"is" + *Action* + "ing" before("is", *Action*) suffix(*Action*, "ing")	⟺	*ProgressiveAction* aspect(*Action*, ongoing)
Mover + *Motion* + *Direction* before(*Motion*, *Direction*) before(*Mover*, *Motion*)	⟺	*DirectedMotionEvent* direction(*Motion*, *Direction*) mover(*Motion*, *Mover*)

More on Construction Grammar

(Goldberg 1995)

- **Clause-level patterns correspond to basic events**
  - transitive: Agent Action Patient
  - ditransitive (dative): Giver Action Recipient Gift
- **Economical: no explosion of senses**
  - He **pushed** the ball.
  - He **pushed** her the ball.
- **Novel uses handled more robustly**
  - Mary **pushed** the tissue off the table.
  - ?Mary **sneezed** the tissue off the table.
  - *Mary **slept** the tissue off the table.

Embodied Construction Grammar

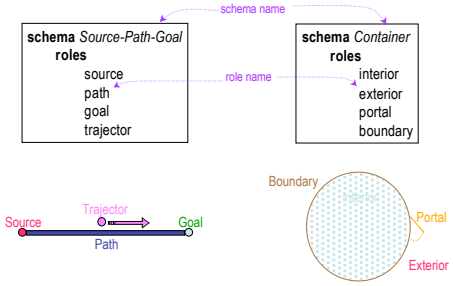
(Bergen and Chang 2002)

- Embodied representations
  - active perceptual and motor schemas (image schemas, x-schemas, frames, etc.)
  - situational and discourse context
- Construction Grammar
  - Linguistic units relate **form** and **meaning/function**.
  - Both constituency and (lexical) dependencies allowed.
- Constraint-based
  - based on feature structure unification (as in HPSG)
  - Diverse factors can flexibly interact.

ECG Structures

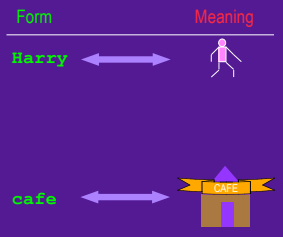
- **Schemas**
  - image schemas, force-dynamic schemas, executing schemas, frames…
- **Constructions**
  - lexical, grammatical, morphological, gestural…
- **Maps**
  - metaphor, metonymy, mental space maps…
- **Spaces**
  - discourse, hypothetical, counterfactual…

Embodied schemas



These are **abstractions** over sensorimotor experiences.

Embodied constructions



ECG Notation

construction HARRY
form : /hEriy/
meaning : Harry

construction CAFE
form : /k^{h}aefej/
meaning : Cafe

Constructions have **form** and **meaning** poles that are subject to type constraints.

Representing constructions: TO

construction TO
form
self$_f$.phon ← /t^{h}u^{w}/
meaning
evokes
Trajector-Landmark **as** tl
Source-Path-Goal **as** spg
constraints:
tl.trajector ↔ spg.trajector
tl.landmark ↔ spg.goal

local alias

identification constraint

The meaning pole may **evoke** schemas (e.g., image schemas) with a local alias. The meaning pole may include constraints on the schemas (e.g., **identification constraints** ↔).

The INTO construction

TO vs. INTO:
INTO adds a *Container* schema and appropriate bindings.

construction INTO
form
self$_f$.phon ← /Int^{h}u^{w}/
meaning
evokes
Trajector-Landmark **as** tl
Source-Path-Goal **as** spg
Container **as** cont
constraints:
tl.trajector ↔ spg.trajector
tl.landmark ↔ cont
cont.interior ↔ spg.goal
cont.exterior ↔ spg.source

Constructions with constituents: The SPATIAL-PHRASE construction

construction SPATIAL-PHRASE
constructional
constituents
sp : Trajector-Landmark
lm : Thing
form
sp$_f$ *before* lm$_f$
meaning
sp$_m$.landmark ↔ lm$_m$

local alias

order constraint

identification constraint

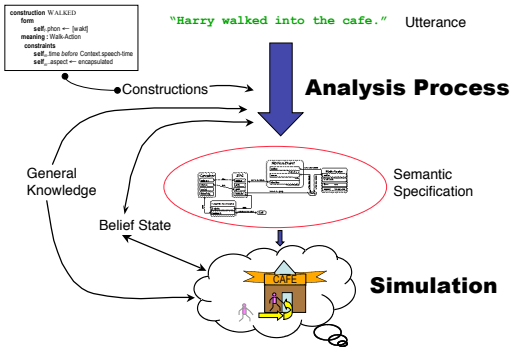
Constructions may also specify **constructional constituents** and impose form and meaning constraints on them:
- –order constraints
- –identification constraints

An argument structure construction

construction DIRECTED-MOTION
subcase of Pred-Expr
constructional
constituents
a : Ref-Exp
m: Pred-Exp
p : Spatial-Phrase
form
a_f *before* m_f
m_f *before* p_f
meaning
evokes Directed-Motion **as** dm
$self_m$.scene ↔ dm
dm.agent ↔ a_m
dm.motion ↔ m_m
dm.path ↔ p_m

schema *Directed-Motion*
roles
agent : Entity
motion : Motion
path : SPG

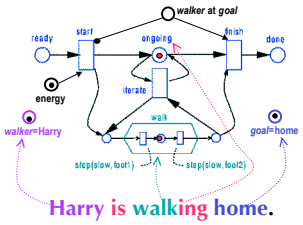
Simulation-based language understanding



Language sets simulation parameters

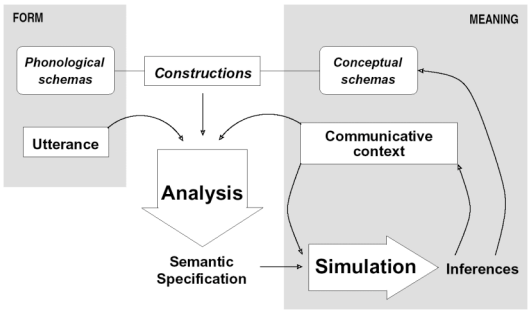
Constructions can:

- specify which schemas and entities are involved in an event, and how they are related
- profile particular stages of an event
- set parameters of an event

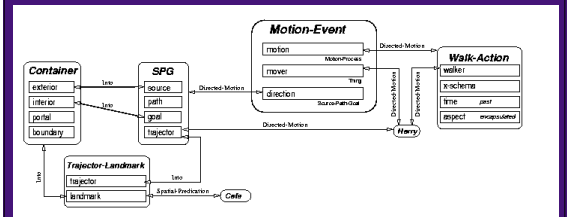


Harry is walking home.

Language Understanding Process



Simulation specification



A simulation specification consists of:
- schemas evoked by constructions
- bindings between schemas

Embodied Construction Grammar provides formal tools for linguistic description and analysis motivated largely by cognitive/functional concerns.

- **A shared theory and formalism for different cognitive mechanisms**
  –Constructions, metaphor, mental spaces, etc.
- **Precise specifications of structures/processes involved in language understanding**
- **Bridge to detailed simulative inference using embodied representations**

ECG applications

- Grammar
  - Spatial relations/events (Bergen & Chang 1999; Bretones et al. In press)
  - Verbal morphology (Gurevich 2003, Bergen ms.)
  - Reference: measure phrases, construal resolution, reflexive pronouns (Dodge and Wright 2002), (Porzel & Bryant 2003), (Sanders 2003)
- Semantic representations / inference
  - Aspectual inference (Narayanan 1997; Chang, Gildea & Narayanan 1998)
  - Perspective / frames (Chang, Narayanan & Petruck 2002)
  - Metaphorical inference (Narayanan 1997, 1999)
  - Simulation semantics (Narayanan 1997, 1999)
- Language acquisition
  - Lexical acquisition (Regier 1996, Bailey 1997)
  - Multi-word constructions (Chang 2004; Chang & Maia 2001)

3. Understanding Metaphorical language (KARMA)

How do I love thee?
(Metaphors for love…)

Patient
Physical force
Bond
Captive animal
Commodity
Fire
Fluid in container
Hidden object
Insanity
Journey
Magic
Natural force
Nutrient
Opponent
Rapture
Unity
War

Let me count the ways…

- **They have a strong, healthy marriage.** (patient)
- **They gravitated to each other immediately.** (force)
- **Money can't buy you love.** (commodity)
- **I'm burning up.** (fire)
- **He poured out his affections on her.** (fluid in container)
- **She couldn't hold in her love for him any longer.** (fluid in container)
- **She found love in all the wrong places.** (hidden object)
- **You've got to hide your love away.** (hidden object)
- **She drives me crazy.** (insanity)
- **She was overcome by love.** (external force)
- **Love took complete control over him.** (external force)
- **Our relationship was at a dead end.** (journey)
- **They were sickeningly sweet together.** (nutrient)
- **She pursued him relentlessly.** (war)
- **He made an ally of her mother.** (war)

The Embodiment Hypothesis

- Basic concepts and words derive their meaning from embodied experience.
- Abstract and theoretical concepts derive their meaning from metaphorical maps to more basic embodied concepts.

Understanding is Grasping

Physical grasping of an object corresponds to mental understanding of an idea

- One can *grasp ideas*.
- One can begin to grasp an idea, but not quite get a hold of it.
- If you fail to grasp an idea, it can go right by you — or over your head!
- If you grasp it, you can turn it over in your mind.
- You can't hold onto an idea before having grasped it.

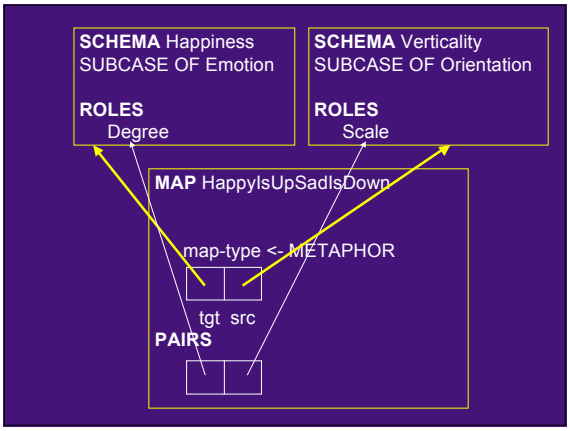
Reasoning about **physical grasping** can be mapped by conceptual metaphor onto abstract reasoning patterns.

Metaphor, defined

- A **metaphor** is a **mapping** from a **source domain** to a **target domain**
  - **Source** domain: typically concrete/sensorimotor
  - **Target** domain: typically abstract
  - Both source and target domains are structured by schemas and frames
- **A simple example:**

  I've been feeling quite ***depressed*** of late.

  (Happy is Up; Sad is Down)



Metaphor understanding system

- **Task: Interpret simple discourse fragments/blurbs**
  - France fell into recession. Pulled out by Germany
  - Economy moving at the pace of a Clinton jog.
  - US Economy on the verge of falling back into recession after moving forward on an anemic recovery.
  - Indian Government stumbling in implementing Liberalization plan
  - Moving forward on all fronts, we are going to be ongoing and relentless as we tighten the net of justice.
  - The Government is taking bold new steps. We are loosening the stranglehold on business, slashing tariffs and removing obstacles to international trade.

Metaphor understanding system

Indian Government stumbling in implementing liberalization plan

Input

Event	Domain	Actor	Aspect
stumble(IG)	Liberalization Plan	Indian Gov. (IG)	present-progressive

Output

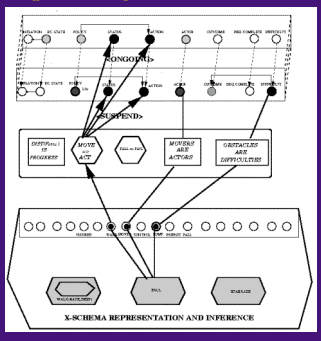
Event	Domain	*Context*	*Status*	*Outcome*	*Goal*
stumble (IG)	Liberaliza-tion Plan	Ongoing plan, **difficulty**	**inter-rupted(.8)**	**failure (.7)**	*free-trade, deregula-tion*

Metaphor system architecture

Target domain

Metaphor maps

Source domain



(Narayanan 1997)

The Event Structure Metaphor

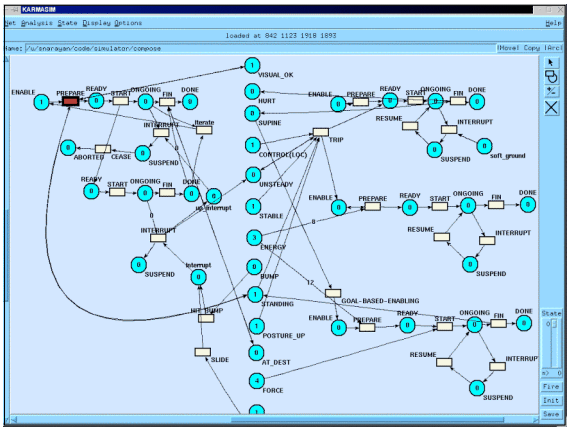
Motion and manipulation concepts map to abstract actions:

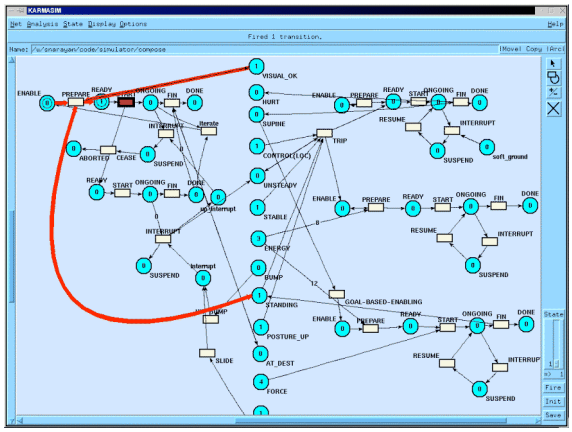
- **States are Locations**
- **Changes are Movements**
- **Causes are Forces**
  - force-dynamic patterns of causation
- **Actions are Self-propelled Movements**
  - speed, step size (mapped parameters)
- **Means are Paths**
  - *crossroads*
- **Difficulties are Impediments to Motion**
- **Long-term, Purposeful Activities are Journeys**
  - *set out, back on track…*

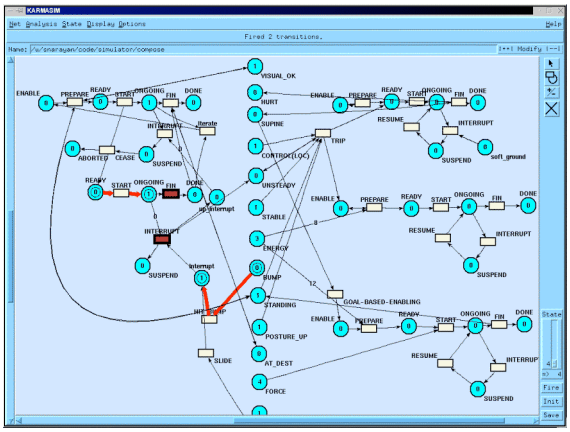
Simulation Semantics

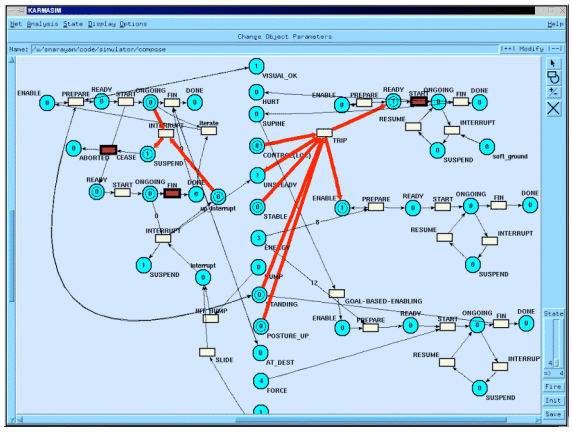
- **execution-based model of events/processes**
  - tractable, distributed, concurrent, context-sensitive
- **X-schemas provide natural model of**
  - resource consumption/production
  - goals, preconditions, effects
  - hierarchical events (multiple granularities)

[See previous lecture for details!]









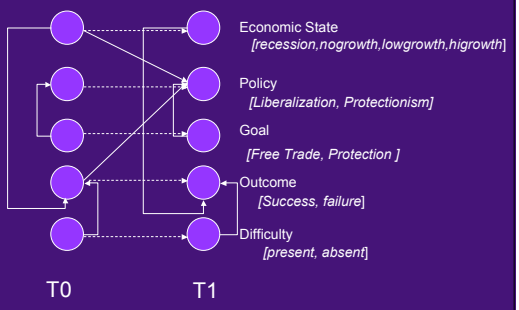
Domain-specific (target) frame

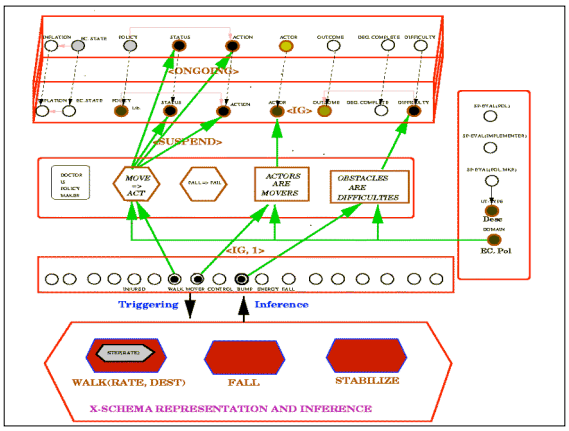
- Simple knowledge about Economics
  - Factual (US is a market economy)
  - Correlational (High Growth => High Inflation)
- Key requirements:
  - Represent **background knowledge** of economics
    - inherent structure and constraints
  - Combine target domain with metaphoric (and other) **projections from multiple source domains**
  - Compute **global impact** of new observations (from both direct input and metaphoric inferences)

Dynamic Bayes Nets

- **Dynamic Bayesian Networks** (DBNs) are an extension of Bayesian networks for modeling dynamic systems
  - state at time t is represented by a set of random variables
  - state at time t is dependent on states at previous time steps
  - first-order Markovian:
    must represent transition distribution $P(Z_{t+1} \mid Z_t)$
- E.g.: 2-time-slice Bayesian network fragment (2-TBN) B_{t+1}
  - variables from Z_{t+1} whose parents are variables from Z_t and/or Z_{t+1}
  - variables from Z_t with no parents
  - assume process is stationary

A Simple DBN for Economics





Results

- **Model implemented/tested on discourse fragments**
  - 150 newspaper stories in international economics
  - Sources: WSJ, NYT, Economist
- **Motion terms provide inferences about abstract plans/actions**
  - Uncertainty in events, dynamic changes in goals, resources
    - sluggish, fall, off-track, no steam
  - Evaluation of policies and economic actors, communicative intent
    - strangehold, bleed
  - Complex, context-sensitive and dynamic economic scenarios
    - stumble, slide, slippery slope
  - Complex event structure and aspectual information
    - on the verge of, sidestep, giant step, small steps, ready, set out, back on track
- **Diverse inferences modeled via simulation + belief propagation**
  - X-schema simulation produces **reflex, automatic inferences**
  - Bindings capture **metaphorical mappings** from source to target domain
  - **Belief propagation** produces additional inferences

Embodiment and Computation

- **Embodiment motivated by convergent constraints across disciplines**
  - Imaginative simulation in language use
- **Sharper notion of embodiment possible using computational representations**
  - ECG formalizes ideas from cognitive and constructional approaches to grammar
- **Unified framework for analysis of disparate phenomena**

Implications

- **Simulation is needed to understand *all language*, not just concrete language.**
- **Meaning is embodied, not abstract.**
- **Pervasive connections between language and the rest of cognition.**

Turing's take on the problem

"Of all the above fields the **learning of languages** would be the most impressive, since it is the most human of these activities.

This field seems however to depend rather too much on **sense organs and locomotion** to be feasible."

Alan M. Turing
Intelligent Machinery (1948)