ThoughtTreasure, the hard common sense problem, and applications of common sense

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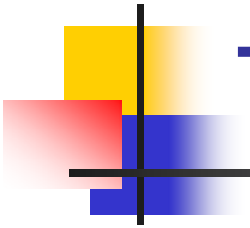
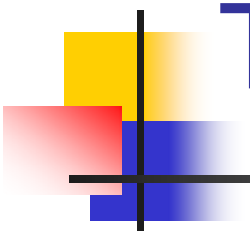
*Work performed while at Signiform



Talk plan

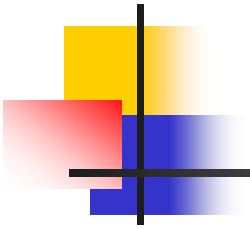
- ThoughtTreasure overview
- ThoughtTreasure and the hard common sense problem
- Applications of common sense
  - SensiCal*
  - NewsForms

*Work performed at the MIT Media Lab and Signiform



ThoughtTreasure

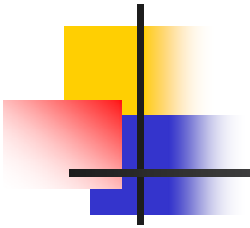
- Common Sense knowledge base
- Architecture for natural language understanding
- Uses multiple representations: logic, finite automata, grids, scripts



ThoughtTreasure KB

- 35,023 English words/phrases
- 21,529 French words/phrases
- 51,305 commonsense assertions
- 27,093 concepts

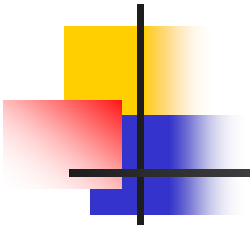
ThoughtTreasure in CycL



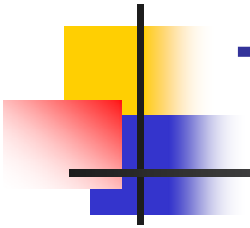
- Including linguistic knowledge
- 547,651 assertions
- 72,554 constants

ThoughtTreasure architecture

80,000 lines of code



- Text agency
- Syntactic component
- Semantic component
- Generator
- Planning agency
- Understanding agency



ThoughtTreasure applications

- Commonsense applications
- Simple factual question answering

```
> What color are elephants? They are gray.
> What is the circumference of the earth?
40,003,236 meters.
> Who created Bugs Bunny?
Tex Avery created Bugs Bunny.
```

- Story understanding

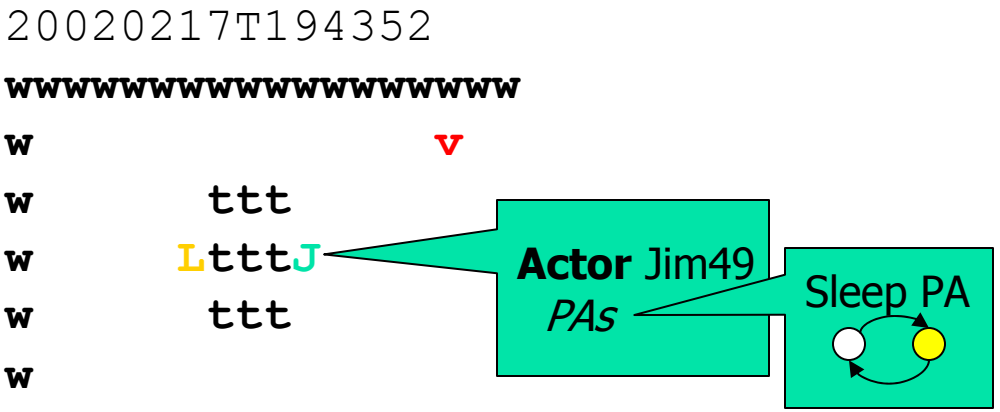
The hard problem: Story understanding

Two robbers entered Gene Cook's furniture store in Brooklyn and forced him to give them $1200.

Who was in the store initially?
And during the robbery?
Did Cook want to be robbed?
Did the robbers tell Cook their names?
Did Cook know he was going to be robbed?
Does he now know he was robbed?
What crimes were committed?

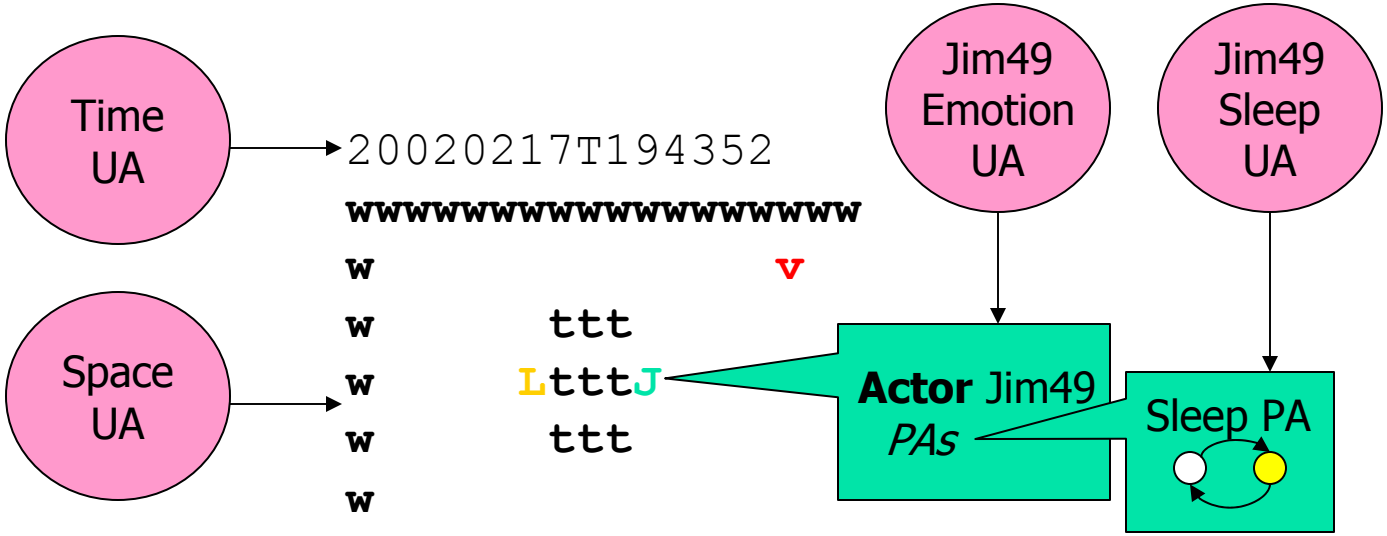
ThoughtTreasure approach to story understanding

1. To build a computer that understands stories, build a computer that can construct simulations of the states and events described in the story.

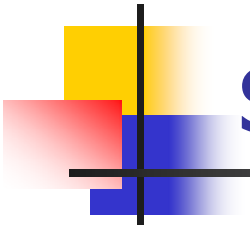


ThoughtTreasure approach to story understanding

2. Modularize the problem by having different agents work on different parts of the simulation.



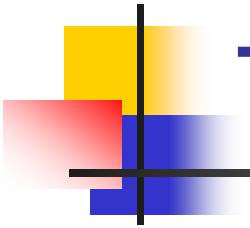
Story understanding by simulation



- Read a story
- Maintain a simulation = model of story
- Answer questions

The debate in psychology

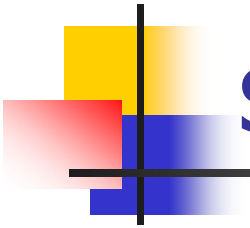
- People reason using mental models
  Johnson-Laird, Philip N. (1993). *Human and machine thinking.*
- People reason using inference rules
  Rips, Lance J. (1994). *The psychology of proof*.



The debate in AI

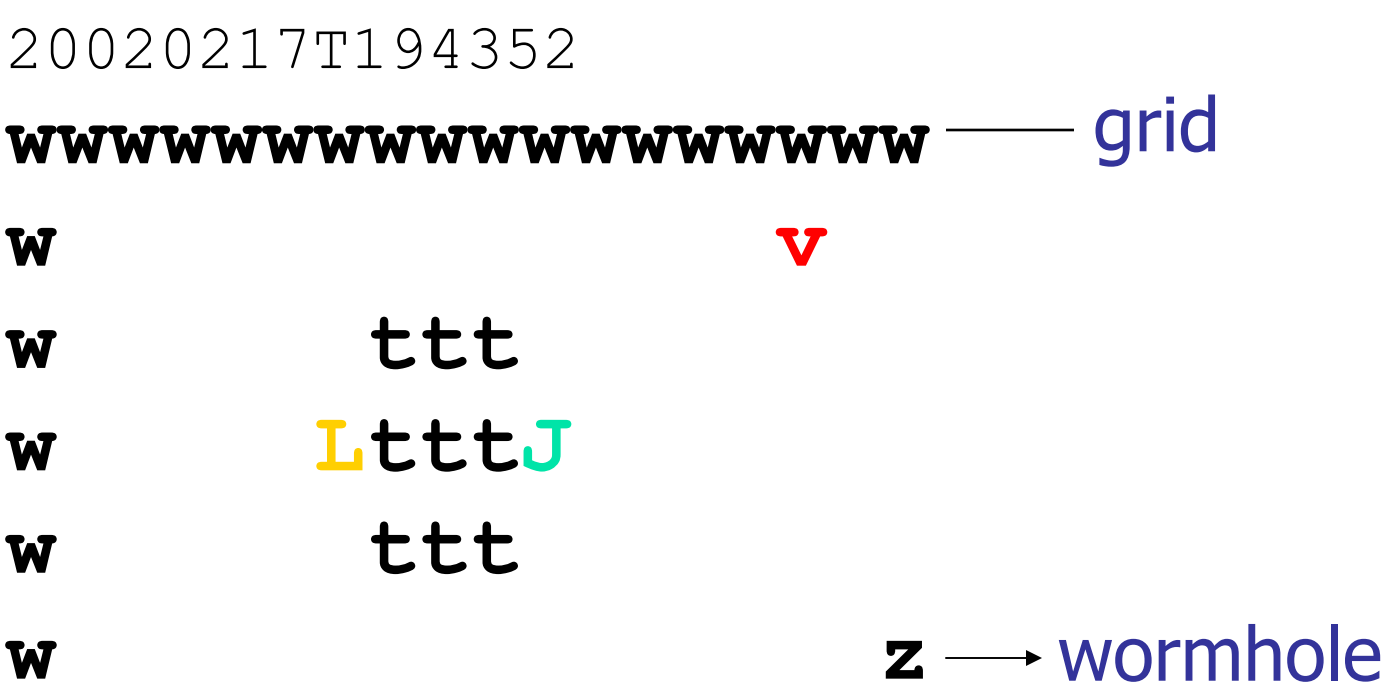
- AI programs should use lucid representations
  Levesque, Hector (1986). Making believers out of computers.
- AI programs should use indirect representations
  Davis, Ernest (1991). (Against) Lucid representations.
- AI programs should use diverse representations
  Minsky, Marvin (1986). *The society of mind*.

Story understanding by simulation



- A simulation is a sequence of states
- A state is a snapshot of the mental world of each story character and the physical world

Physical world: Grids and wormholes



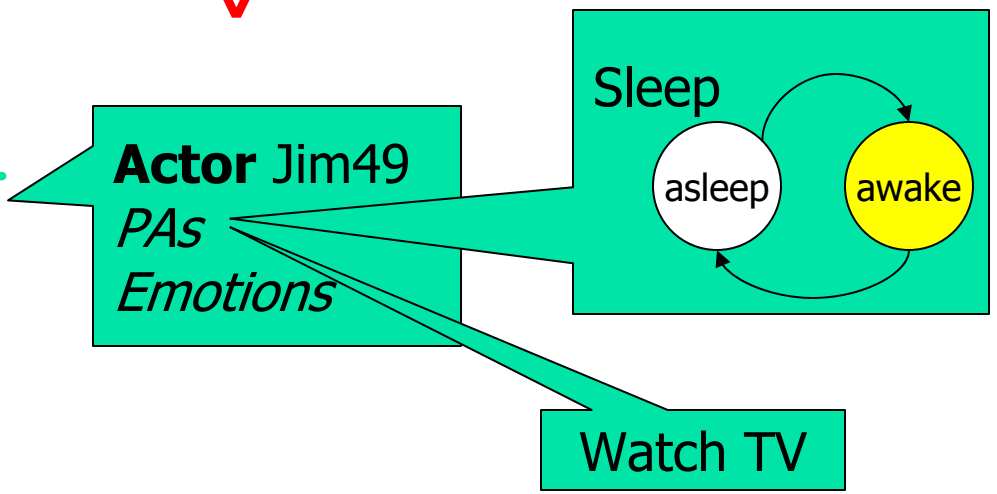
Physical world: Objects

```
20020217T194352
wwwwwwwwwwwwwwwwwwww
w                  v
w        ttt
w      LtttJ
w        ttt
w
```

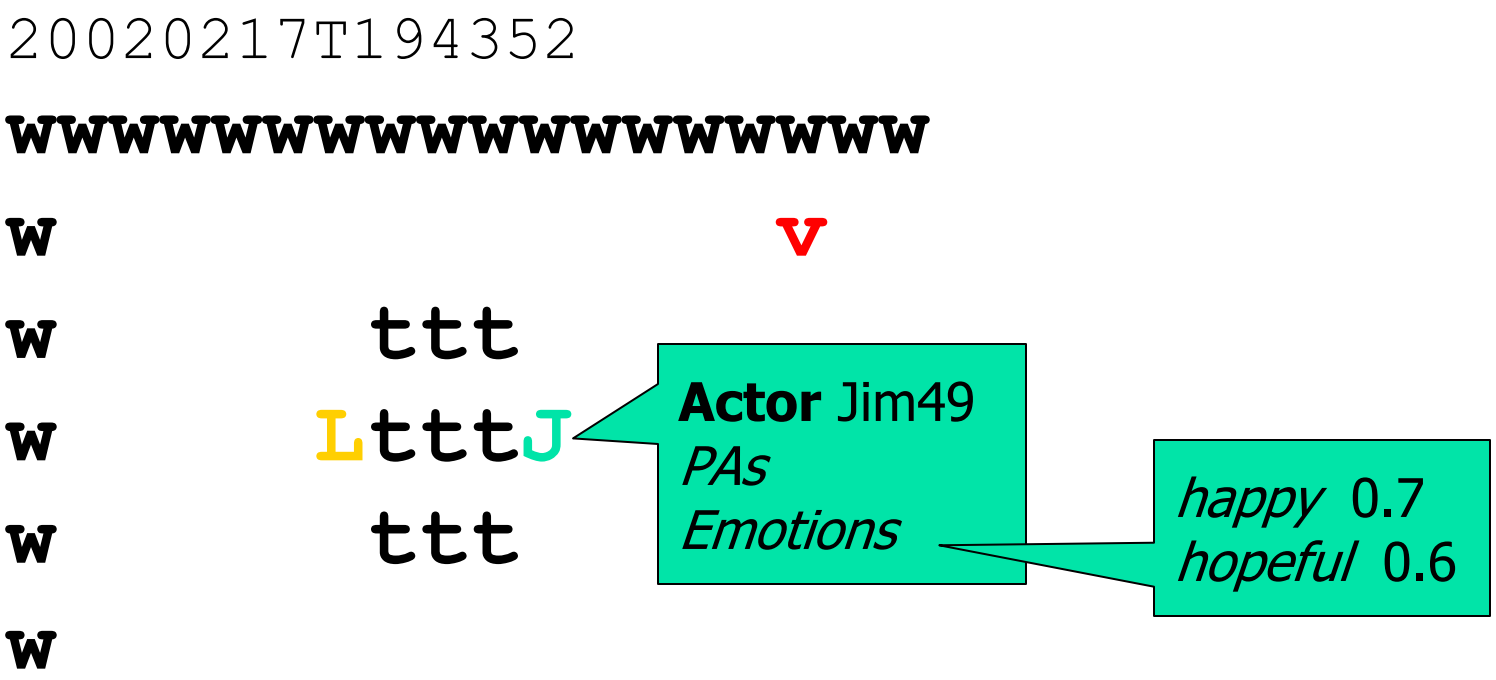
Object TVSet31
State Off
Channel 24

Mental world: Planning agents

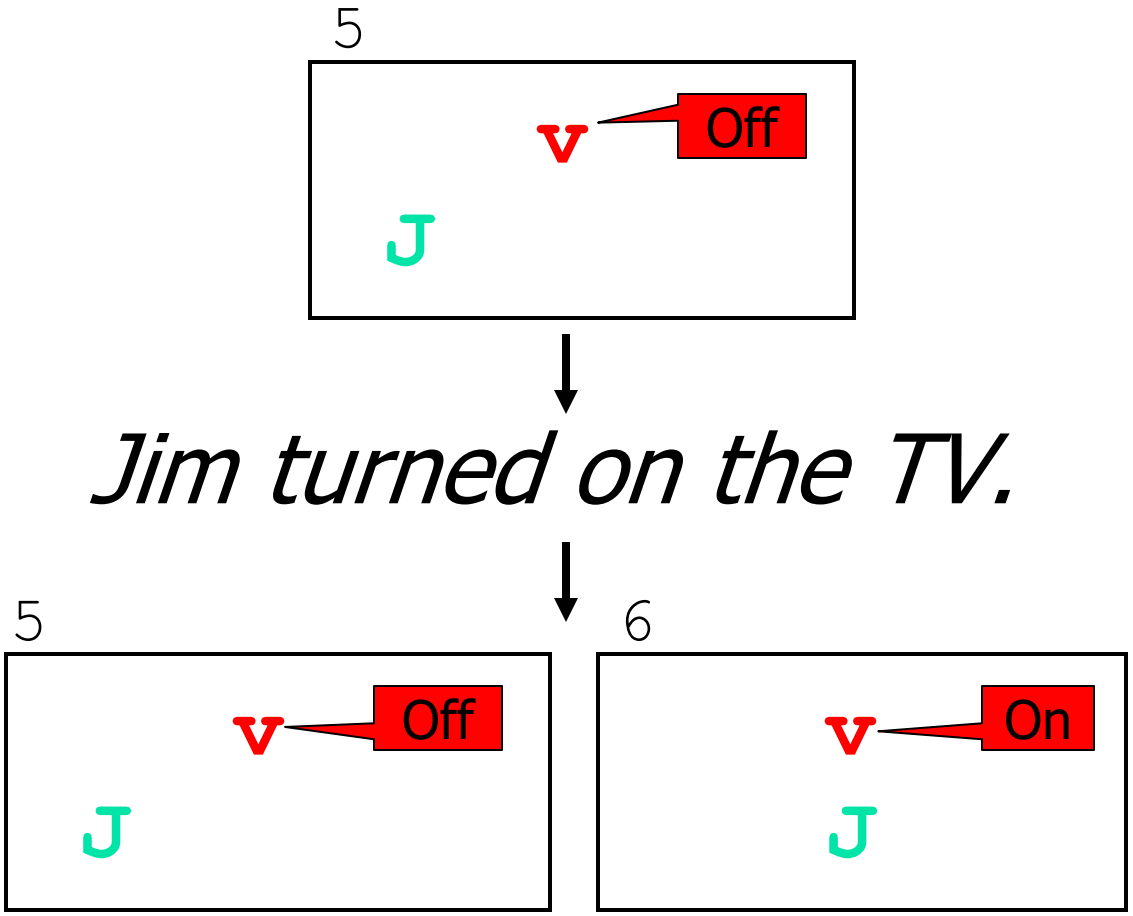
```
20020217T194352
wwwwwwwwwwwwwwwwwwww
w                  v
w                ttt
w              LtttJ
w                ttt
w
```



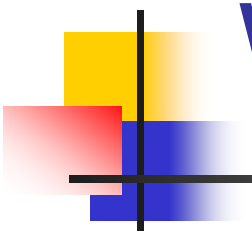
Mental world: Emotions



Each input updates the simulation



Why this approach?



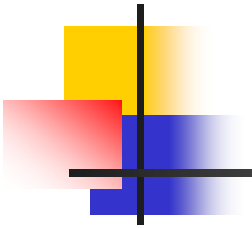
- Easy question answering by reading answers off the simulation
- Convenient modularization by components of the simulation

Modularization

One understanding agent per simulation component

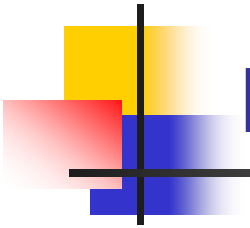
- Space
- Time
- Actor – one per story character
- Device – one per device
- Goal
  Emotion
  Sleep
  Watch TV
  …
  – one per story character

Understanding agents



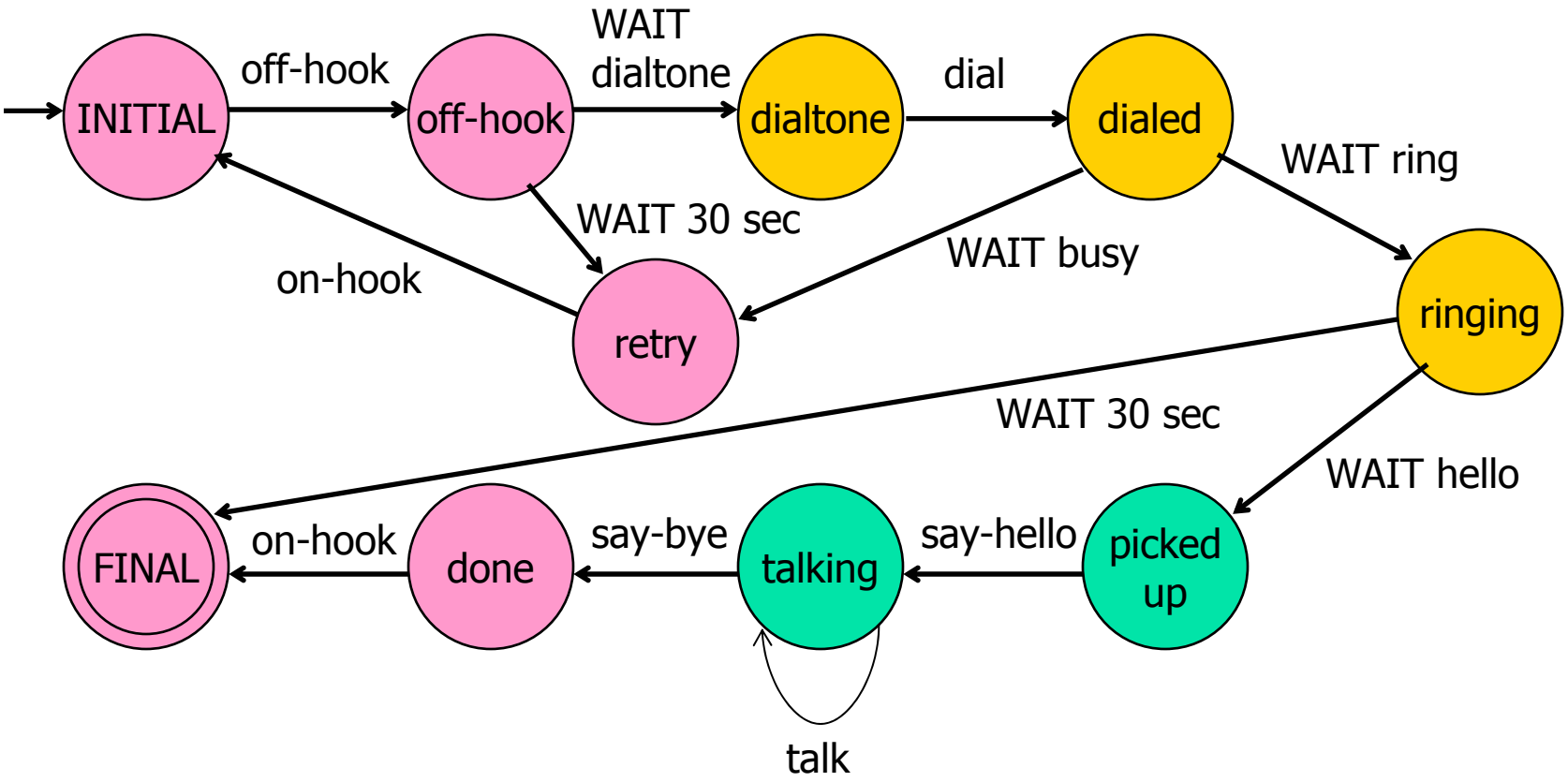
- Space UA – *Jim walked to the table.*
- Emotion UA – *Jim was happy.*
- Sleep UA – *Jim was asleep.*
- TV device agent – *The TV was on.*

Detail on ThoughtTreasure representations



- Planning agents
- Grids and wormholes

PhoneCall planning agent



SubwayPlatform grid

```
==metro-RD-2d//|col-distance-of=5m|row-distance-of=10m|
level-of=-2u|orientation-of=north|GS=
GGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGG
GGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGG
    w9                                                w
    w                                                 w
    w  BBBBC  BBBB   BBBB   BBBB  CBBBB      uu3
    wwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwww
    wwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwww
.
u:stairs-up
w:wall
B:bench
G:&metro-Creteil-tracks
3:&metro-RD-Creteil-entrance1
9.wuG:&metro-RD-Creteil-platform
```

SubwayPlatform grid

```
==metro-RD-2d//|col-distance-of=5m|row-distance-of=10m|
level-of=-2u|orientation-of=north|GS=
GGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGG
GGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGG
     w**************************************w
     w**************************************w
     w**************************************uu3
     wwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwww
     wwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwww
.
u:stairs-up
w:wall
B:bench
G:&metro-Creteil-tracks
3:&metro-RD-Creteil-entrance1
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```

SubwayPlatform grid

```
==metro-RD-2d//|col-distance-of=5m|row-distance-of=10m|
level-of=-2u|orientation-of=north|GS=
GGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGG
GGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGG
    w                                                 w
    w                                                 w
    w  BBBBC  BBBB   BBBB   BBBB  CBBBB              uu3
    wwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwww
    wwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwww
.
u:stairs-up
w:wall
B:bench
G:&metro-Creteil-tracks
3:&metro-RD-Creteil-entrance1
9.wuG:&metro-RD-Creteil-platform
```

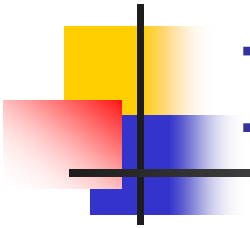
wormhole

SubwayTicketArea grid

```
wwwwwwwwwwwwwwwwwwwwwwwwwwwww
ddT                         uuu
w          wwwwwwww           w
w          w      Xw          w
w         BfA      w          w
w          wwwwwwww           w
w                             w
wwwTwwwwwwwwwwwwwwwwwwwwwwwww
   d
3
```

wormhole →

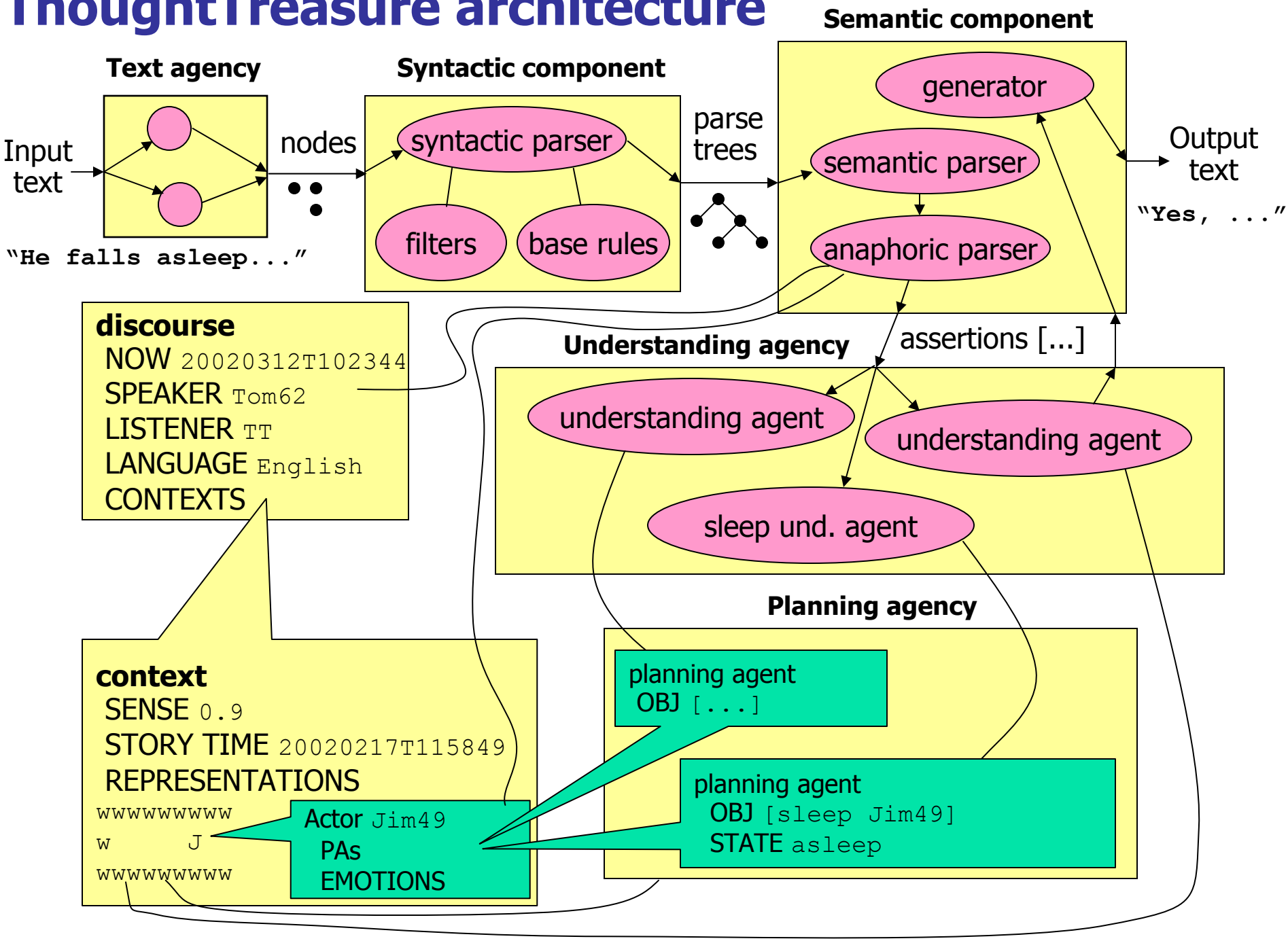
```
d:stairs-down
u:stairs-up
w:wall
A:employee-side-of-counter
B:customer-side-of-counter
T:automated-turnstile
X.wf:&metro-RD-ticket-booth
3:&metro-RD-Creteil-entrance1
```



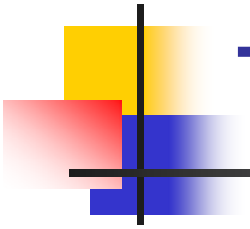
Inferences from grids

- Distance between objects
- Relative position of objects (left, right, front, back)
- Whether two actors can see or hear each other
- Whether there is a path from one location to another

ThoughtTreasure architecture



Simple stories handled by ThoughtTreasure



- Two children, Bertie and Lin, in their playroom and bedrooms
- Jenny in her grocery store
- Jim waking up and taking a shower in his apartment

Story understanding by simulation

```
> Lin walks to her playroom.
Ts = 20020217T115849
wwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwww
w                   w                BBBBw
w                   w                BBBBw
w Lin :-) awake                        w
w                   wwwwwwwwwwwwwwwwwwww
w                                      w
w                   w    LLLL          w
w                   w    LLLL          w
wwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwww
```

Story understanding by simulation

```
> She is where?
She was in the playroom of the
apartment.
```

Story understanding by simulation

```
> She walks to her bedroom.
Ts = 20020217T115902
wwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwww
w                   w                BBBBw
w                   w                BBBBw
w       ..                             w
w          ...      wwwwwwwwwwwwwwwwwww
w             .........Lin :-) awake w
w                   w    LLLL          w
w                   w    LLLL          w
wwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwww
```

Story understanding by simulation

> She is where?

She was in her bedroom.

> She is near her bed?

Yes, she is in fact near the bed.

Story understanding by simulation

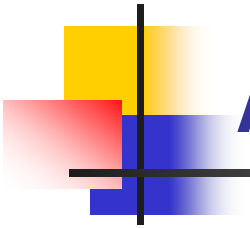
```
> She falls asleep.
Ts = 20020217T120034
wwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwww
w                   w                BBBBw
w                   w                BBBBw
w                                       w
w                   wwwwwwwwwwwwwwwwwww
w                        .              w
w                   w    .LLL           w
w                   w Lin :-) asleep w
wwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwww
```

Story understanding by simulation

```
> She is asleep?
Yes, she was in fact asleep.
> She is awake?
No, she is not awake.
> She was in the playroom
when?
She was in the playroom of
the apartment two minutes
ago.
```

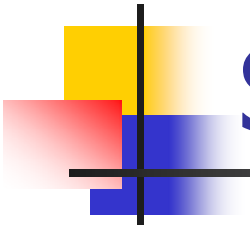
Scaling up ThoughtTreasure

- Add more grids, planning agents, understanding agents
- Use automated and semi-automated techniques for acquisition
- Use Open Mind for acquisition



Applications of common sense

- SensiCal
- NewsForms



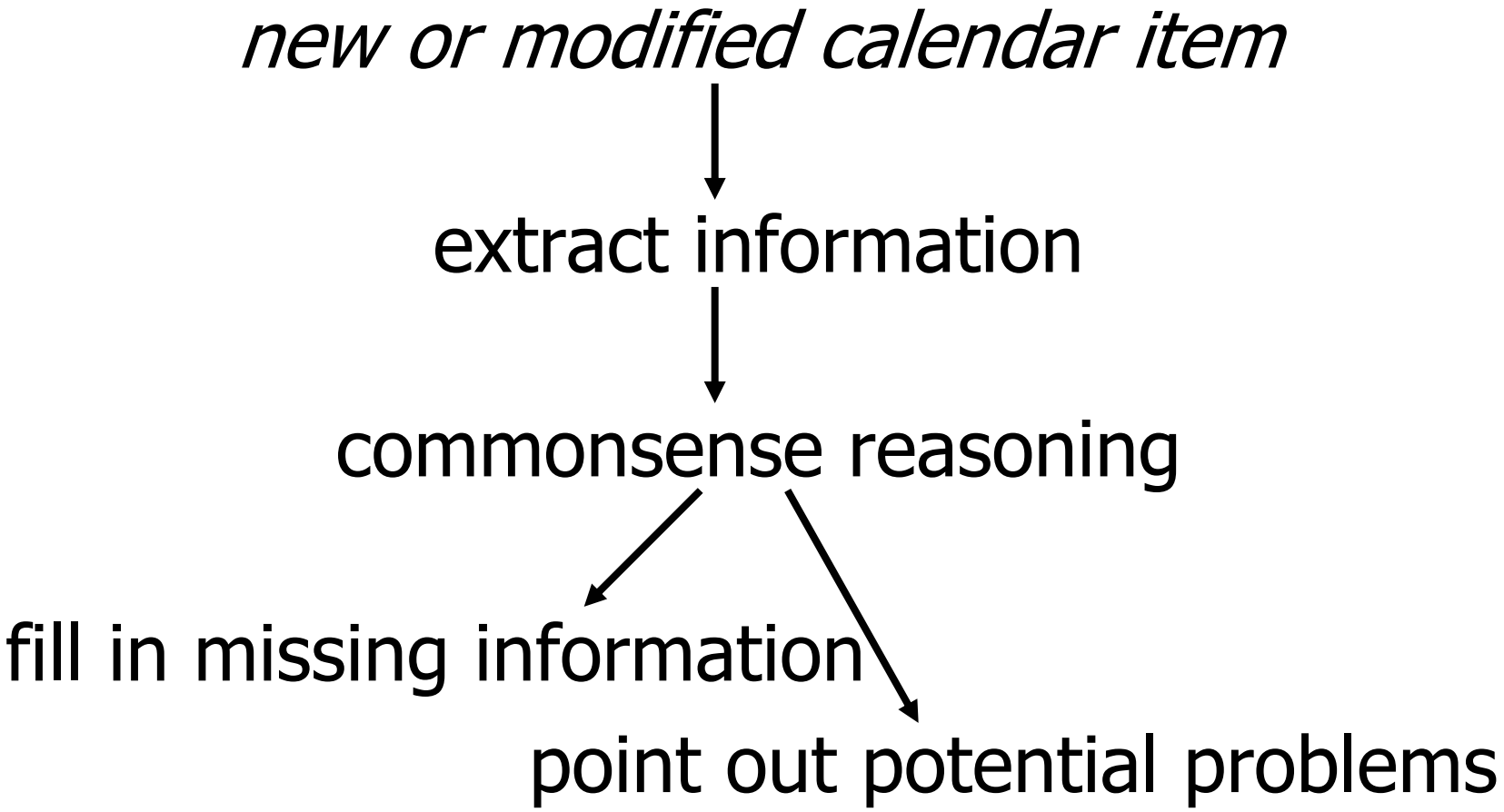
SensiCal

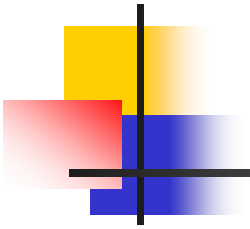
- Smart calendar application
- Speeds entry by filling in information
- Points out obvious blunders

SensiCal


You are taking Lin who is vegetarian to a steakhouse?
OK
File Edit Item Repe
Help
May
Sun Mon Tue W
1
2 3 4 5 6 7 8
9 10 11 12 13 14 15
16 17 18 19 20 21 22
23 24 25 26 27 28 29
30 31
Prev
Today
Next
10:00am
11:00am
12:00pm
lunch w/lin at frank's steakhouse
1:00pm

Operation of SensiCal





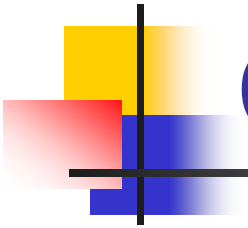
Information extracted

- Type of item
- Participants
  - role
  - name
- Location
  - venue name and type
  - earth coordinates

Information extracted

```
Text: lunch w/lin at frank's steakhouse
StartTs: 20020528T120000
EndTs:   20020528T130000
```

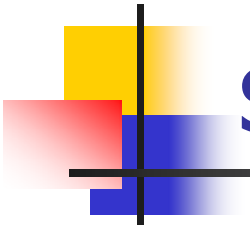
```
ItemType:        meal
MealType:        lunch
Participant:     Lin
Venue:           Frank's Steakhouse
VenueType:       steakhouse
```



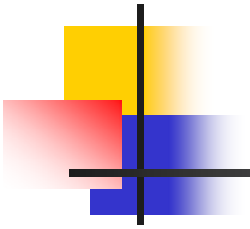
Common sense of calendaring

- People grocery shop in grocery stores
- Vegetables are found in grocery stores
- A person can't be in two places at once
- Allow sufficient time to travel from one location to another
- People typically work during the day and sleep at night
- People do not usually attend business meetings on holidays
- Lunch is eaten around noon for an hour
- Don't eat at restaurants that serve mostly food you avoid
- Vegetarians avoid meat
- A steak house serves beef
- Beef is meat
- You can't visit a place that's not open
- Restaurants do not generally serve dinner after 11 pm
- Museums are often closed on Mondays
- …

Representation of common sense in ThoughtTreasure

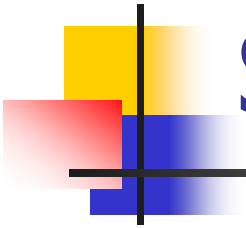


- Assertions
- Scripts
- Grids
- Procedures
  - Trip planning agent
  - Path planner



Assertions

```
[performed-in eat-dinner restaurant]
[serve-meal steakhouse beef]
[avoid vegetarian meat]
```



Scripts

- Roles

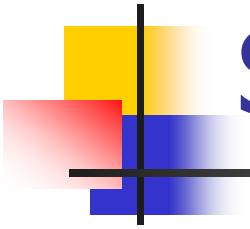
```
[role-of visit-museum museum-goer]
[role-of wedding-ceremony bride]
```

- Sequence of events

```
[event01-of go-blading
    [put-on blader rollerblades]]
[event02-of go-blading
    [blade blader]]
```

- Time and duration

```
[min-value-of eat-lunch 11am]
[max-value-of eat-lunch 2pm]
[duration-of eat-lunch 1hrs]
```



Scripts

- Cost

```
[cost-of take-subway $1]
```

- Entry conditions

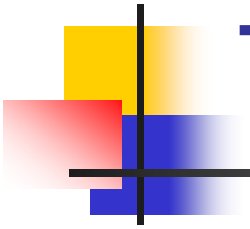
```
[entry-condition-of sleep
    [sleepy sleeper]]
```

- Goals

```
[goal-of telephone-call
    [talk calling-party called-party]]
```

Grids

```
VVVVVSSSwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwww
VVVVVSS2q                                              fnffw
VVVVVSSSq                                              fxffw
VVVVVSSSw   ttt        ffffmffff                       ffffw
VVVVVSSSw   tttB    sssssssssssssssssssssssssssss      ffffw
VVVVVSSSw cArtt     sssssssssssssssssssssssssssss      fuffw
VVVVVSSSw   ttt            z        y                  ffffw
VVVVVSSSw1                                             fpffw
VVVVVSSSw                                              ffffw
VVVVVSSSwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwww
.
A:employee-side-of-counter       B:customer-side-of-counter
c:side-chair                     f:store-refrigerator
m:Sprite                         n:carrot
n:greenhouse-lettuce             n:tomato
n:onion                          ...
```



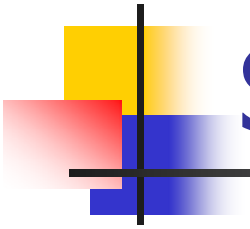
Trip planning agent

1. walk to subway stop in **`street`** grid (00:10)
2. take subway on **`subway`** grid (00:20)
3. board plane in **`airport`** grid (01:00)
4. fly along Atlantic Ocean in **`earth`** grid (07:00)

Total (08:30)

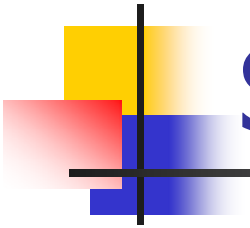
Path planner

```
&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&
&                                                               wwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwww&
&                                                     wwwwwwwwwww  tttwsss   ht     Aswcccccccccw&
&                                   wwwwwwwwwwwwwwwwwww         w  tttwmss            wcccccccccw&
&wwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwccccccccw        w         w   smwmss            wcc       w&
&w  llllllll ss   g Ecccc  sssssssswcccccccccw        w         w   smwmss            wcv       w&
&wa llllllll ss       s    sssssssswcccccccccw        wwww   wwwww   wwmss            wcc       w&
&wA  Ec                           sswccccccccw                        wwwww    wwwwwwwwww    wwww&
&w   cc                           sswccccccccw                                                  w&
&wr                               sswwwwwwwwww                                                  w&
&wr                                 w       ****************************************            w&
&wr                             ************  wwwwwwwwwwwwwwwwwwwwwwwwwwtttttttttttl*          lw&
&w                   ***********               ssw                    wttttttttttttt*          tw&
&w       ************                          ssw                    wttttttttttttt*           w&
&w ******                           w          ssw                    wA    s      *   EEEEEEEEEw&
&w                                  w          Rsw                    w           *    EEEEEEEEEw&
&w            s                     w           sw                    wls        *     EEEEEEEEEw&
&w         ttttttttt                wwwwww    wwww                    w s       *      EEEEEEEEEw&
&wr       sttttttttts      ss     ssw            w                    w s       *      EEEEEEEEEw&
&wr        ttttttttt       ss     ssw                                 w         *      EEEEEEEEEw&
&wr            s           ss      Aw                                 w         *      EEEEEEEEEw&
&w    s                    ss       w                                 w   E     *      EEEEEEEEEw&
&w  tttt      sssssssssss  ss     rrw                                 w     ttttttEt   EEEEEEEEEw&
&w A          sssssssssss  ss     rrw            w                    w    rrrrr        rrrrr  Aw&
&wwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwww    wwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwww&
&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&
```



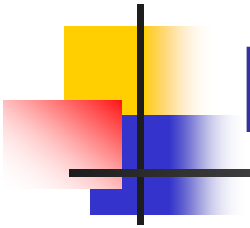
SensiCal status

- Prototype implemented in Tcl and Perl as extension to ical
- Communicates with ThoughtTreasure using ThoughtTreasure server protocol



SensiCal future work

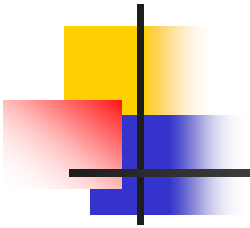
- Add more commonsense knowledge and reasoning
- Hook up to Open Mind



NewsForms

- NewsForms are XML representations of news events
- NewsForms enable numerous commonsense applications

NewsForms for 17 types of events

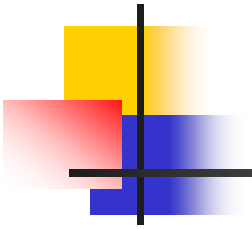


- competitions
- deals
- earnings reports
- economic releases
- Fed watching
- IPOs
- injuries and fatalities
- joint ventures
- legal events

NewsForms for 17 types of events

- medical findings
- negotiations
- new products
- management successions
- trips and visits
- votes
- war
- weather reports

NewsForm defines



- Elements for news event types
  Deal, *InjuryFatality*
- Child elements
  Target of *Deal*
  Cause of *InjuryFatality*
- Standard values (#PCDATA)
  Earthquake, *Fire*

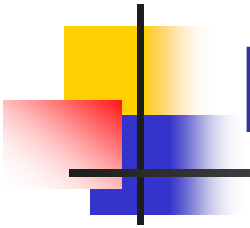
NewsForm DTD

```
<?xml version="1.0" encoding="UTF-8"?>
<!- NewsForm document type definition -->
<!ELEMENT Deal (Acquirer|Advisor|DealStatus|
  DealValue|SharePrice|Stake|StockRatio|
  Successor|Survivor|Target)*>
<!--Rumored/InTalks/Agreed/Approved/
  Completed/Failed -->
<!ELEMENT DealStatus %STRING>
<!ELEMENT InjuryFatality (AccidentCar|
  AccidentPlane|AtLocation|Boat|Cause|
  CauseEvent|Hospitalized|Injured|
  InjuredCount|Killed|KilledCount|
  LandedPlane|Source|SurvivedBy)*>
```

…

Sample NewsForm

```
<NewsForm>
  <Head>
    <DatelineTime>19990125T181917Z</DatelineTime>
  </Head>
  <InjuryFatality>
    <Cause>Earthquake</Cause>
    <InjuredCount>900</InjuredCount>
    <KilledCount>143</KilledCount>
    <Source><Function>CivilDefenseOfficial
      </Function></Source>
    <AtLocation>
      <Country>COL</Country>
      <Latitude>4.29</Latitude>
      <Longitude>-75.68</Longitude>
    </AtLocation>
  </InjuryFatality>
</NewsForm>
```



NewsForm applications

- E-commerce
- Portable devices
- Desktop applications

Travel site informs user of earthquake

New York Kennedy (JFK) to Seattle/Tacoma, WA (SEA)

Price: 1 adult @ USD 269.50

Buy Now Flight: Jetblue Airways flight 83 on an Airbus Industrie Jet
Departs: Thursday, March 01
From: New York Kennedy (JFK) at 9:00pm
To: Seattle/Tacoma, WA (SEA) at 11:59pm

Strong Earthquake Rocks Seattle

(02/28/01, 3:47 p.m. ET) By Chris Stetkiewicz and Scott Hillis , Reuters
SEATTLE—An earthquake measuring 7.0 rattled Seattle Wednesday, swaying buildings and forcing the evacuation of thousands from their offices, schools, homes, and hospitals, witnesses said.

Agent redirects order to bankrupt partner

Thursday April 12, 12:57 pm Eastern Time

iTech Capital Notes PinPoint Has Ceased Operations

VANCOUVER, BRITISH COLUMBIA--PinPoint Corporation, a developer of local positioning system technologies, has notified all of its shareholders that it has been unsuccessful in its attempt to raise additional capital required to continue operations. As such, PinPoint has ceased operations and has filed for protection under the bankruptcy laws.

Cell phone informs fan of nearby star

STAR TRACKS

'DEATH' IN NEW YORK: Leading men ANTHONY HOPKINS and BRAD PITT are now in town shooting "Meet Joe Black," a remake of the after-life fantasy "Death Takes a Holiday." Pitt's stunt double gets hit by a car ... so the story can begin.

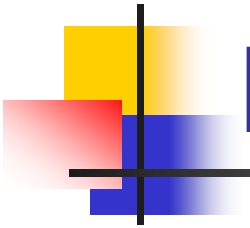
Calendar program informs user of subway outage

Mon	Tue Meeting at MFA	Wed	Thu	Fri

TRAVELING ON THE T > TRANSIT UPDATE

Green Line:

Green Line service on the E train is temporarily suspended this morning due to signal work.



NewsForms status

- NewsForm DTD specified
- NewsExtract text-to-NewsForm converter implemented
- NewsExtract search engine implemented

NewsExtract alpha2

Search for news stories

a Search

Type: Any

Date range: Last 30 days

Map: US

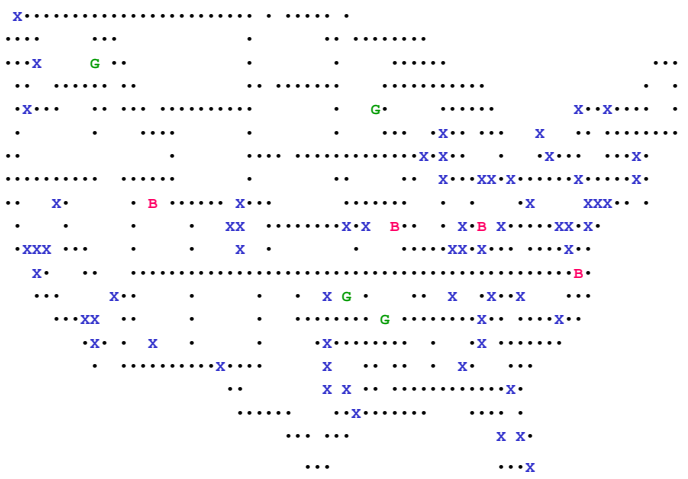
Sort by: Date

About NewsExtract

Questions or comments? webmaster@signiform.com

NewsExtract alpha2

614 matches for **a** (last 30 days)
word count: a:614
Last updated July 14, 2000 04:01:44 EDT



The facts on this page are automatically parsed out of the story text and **may be incorrect.**

20000714

Gene Discovery in Mice May Lead to New Arthritis Treatments (washingtonpost.com)

WashingtonPost NewsForm

MedicalFinding **Illness**: Arthritis

InternetNews - Streaming Media News -- AOL, RealNetworks Team for Streaming

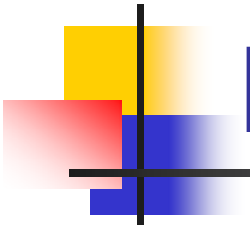
InternetNews.com NewsForm

JointVenture **JointVentureType**: Agreement

Convolve, MIT Sue Compaq, Seagate For $800 Million

TechWeb NewsForm

LegalEvent **Forum**: U S Industries Inc [USI.N] **LegalAction**: File **LegalFiling**: Suit

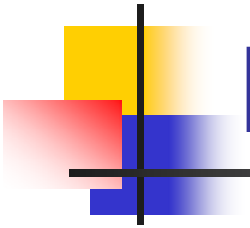


NewsForms future work

- Improve precision/recall of NewsExtract
- Launch distributed human project for realtime NewsForm creation and correction
- Build commonsense applications that use NewsForms

ThoughtTreasure, the hard common sense problem, and applications of common sense

Erik T. Mueller
IBM Research*
*Work performed while at Signiform



Extra slides

ThoughtTreasure vs. Cyc

- ThoughtTreasure inspired by Cyc
- Cyc mostly uses single representation (logic); ThoughtTreasure uses multiple representations (logic, finite automata, grids)
- Recovery of script information from Cyc is difficult:

```
(=> (and (subEvents ?X ?U) (isa ?U Staining))
    (isa ?X WoodRefinishing))
(=> (and (isa ?U ShapingSomething) (subEvents ?U ?X))
    (isa ?X CuttingSomething))
```

ThoughtTreasure scripts are easy to use:

```
[event-of refinish-wood [stain human wood]]
[event-of shape [cut human physical-object]]
```

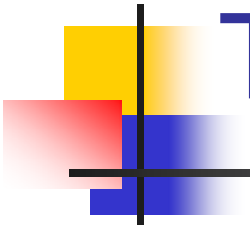
ThoughtTreasure vs. OpenCyc

Analysis of nonlinguistic assertions
http://www.signiform.com/tt/htm/opencyctt.htm

	OpenCyc 0.6.0	**ThoughtTreasure 0.00022**
Hierarchical	62%	56%
Typing	33%	2%
Spatial	0%	4%
Script	0%	4%
Part	0%	2%
Property	0%	1%
Other	5%	31%
Assertions	60,878	51,305

ThoughtTreasure vs. WordNet

- WordNet is lexical, not conceptual; world knowledge, scripts, object properties excluded
- WordNet has separate databases for nouns, verbs, adjectives, adverbs; no prepositions; few relations between databases; *agreement* not connected to *agree*
- WordNet lacks top-level ontology

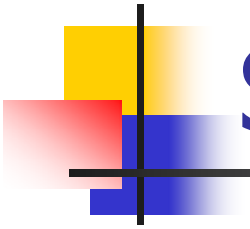


ThoughtTreasure vs. WordNet

- WordNet is monolingual (But see EuroWordNet)
- WordNet weak on argument structure

```
let go of, let go, release
*> Somebody ----s something
*> Somebody ----s somebody
```

- WordNet has no parser, generator, understanding agents



Scripts in ThoughtTreasure

- Scripts proposed in 1970s by Schank & Abelson, Minsky, Wilks
- Few attempts to build database of scripts
- 100 scripts in ThoughtTreasure

Scripts in ThoughtTreasure: Representation based on Schank & Abelson, 1977

- Sequence of events
- Roles, props
- Places
- Entry conditions, goals, results
- Emotions
- Duration, frequency, cost

ThoughtTreasure object: call

[English] telephone call, call, make a telephone call, make a phone call, make a call, give a ring to, give a call to,

telephone, ring up, ring, call up, call, phone up, phone; [French] appeler, téléphoner à

[ako ^ interpersonal-script]

[cost-of ^ NUMBER:USD:1]

[duration-of ^ NUMBER:second:600]

[event01-of ^ [pick-up calling-party phone-handset]]

[event02-of ^ [dial calling-party phone-number]]

[event03-of ^ [interjection-of-greeting called-party calling-party]]

[event04-of ^ [interjection-of-greeting calling-party called-party]]

[event05-of ^ [converse calling-party called-party]]

[event06-of ^ [interjection-of-departure calling-party called-party]]

[event07-of ^ [interjection-of-departure called-party calling-party]]

[event08-of ^ [hang-up calling-party phone-handset]]

[goal-of ^ [near-audible calling-party called-party]]

[performed-in ^ room]

[period-of ^ NUMBER:second:7200]

[r1 ^ human]

[r2 ^ human]

[related-concept-of ^ phonestate]

[role01-of ^ calling-party]

[role02-of ^ called-party]

[role02-script-of ^ handle-call]

[role02-script-of handle-call ^]

[role03-of ^ phone]

[role04-of ^ phone-handset]

[role05-of ^ phone-number]

```
ThoughtTreasure object: mail-letter-at-post-office
[ako ^ mail-letter]
[cost-of ^ NUMBER:USD:0.33]
[duration-of ^ NUMBER:second:600]
[event01-of ^ [pick-up sender snail-mail-letter]]
[event02-of ^ [ptrans sender na post-office]]
[event03-of ^ [wait-in-line sender]]
[event04-of ^ [ptrans-walk sender na postal-counter]]
[event05-of ^ [pre-sequence postal-clerk sender]]
[event05-of ^ [pre-sequence sender postal-clerk]]
[event06-of ^ [hand-to sender postal-clerk snail-mail-letter]]
[event07-of ^ [weigh postal-clerk snail-mail-letter]]
[event08-of ^ [postmark postal-clerk snail-mail-letter]]
[event09-of ^ [post-sequence postal-clerk sender]]
[event09-of ^ [post-sequence sender postal-clerk]]
[event10-of ^ [ptrans sender post-office na]]
[goal-of ^ [owner-of snail-mail-letter recipient]]
[goal-of ^ [s-employment postal-clerk]]
[performed-in ^ post-office]
[period-of ^ NUMBER:second:604800]
[role01-of ^ sender]
[role02-of ^ recipient]
[role03-of ^ snail-mail-letter]
[role04-of ^ post-office]
[role05-of ^ postal-counter]
[role06-of ^ postal-clerk]
```

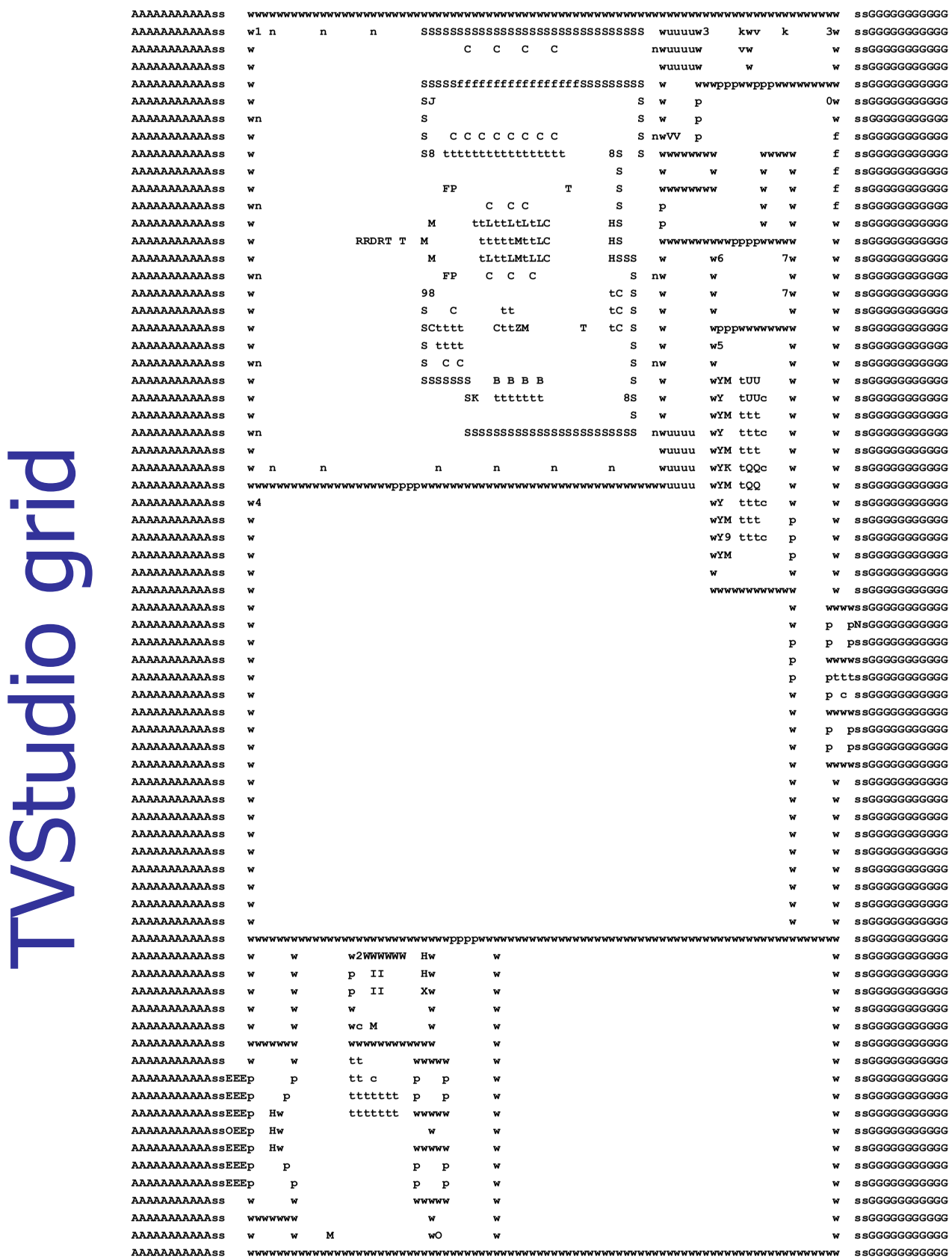
```
ThoughtTreasure object: have-filling-done
[English] have a filling, have a filling done; [French] se faire faire un plombage
[ako ^ dentist-appointment]
[cost-of ^ NUMBER:USD:200]
[duration-of ^ NUMBER:second:3600]
[emotion-of ^ [nervousness role-patient]]
[emotion-of ^ [pain role-patient]]
[event01-of ^ [ptrans role-patient na dental-office]]
[event02-of ^ [ptrans-walk role-patient na waiting-room]]
[event03-of ^ [wait role-patient]]
[event04-of ^ [action-call dental-assistant na role-patient]]
[event05-of ^ [ptrans-walk role-patient waiting-room dental-operatory]]
[event06-of ^ [sit-in role-patient dental-chair]]
[event07-of ^ [inject dentist novocaine mouth]]
[event08-of ^ [wait role-patient]]
[event09-of ^ [drill-tooth dentist tooth dental-drill]]
[event09-of ^ [listen role-patient elevator-music]]
[event10-of ^ [fill-tooth dentist tooth dental-filling]]
[event11-of ^ [ptrans role-patient dental-operatory na]]
[goal-of ^ [p-health role-patient]]
[goal-of ^ [s-profit dentist]]
[performed-in ^ dental-office]
[period-of ^ NUMBER:second:1.5768e+08]
[r1 ^ human]
[role01-of ^ role-patient]
[role02-of ^ dentist]
[role03-of ^ dental-assistant]
[role04-of ^ tooth]
[role05-of ^ mouth]
[role06-of ^ dental-office]
[role07-of ^ waiting-room]
[role08-of ^ dental-chair]
[role09-of ^ dental-operatory]
[role10-of ^ dental-filling]
[role11-of ^ novocaine]
```

Scripts in ThoughtTreasure: Comparison to related work

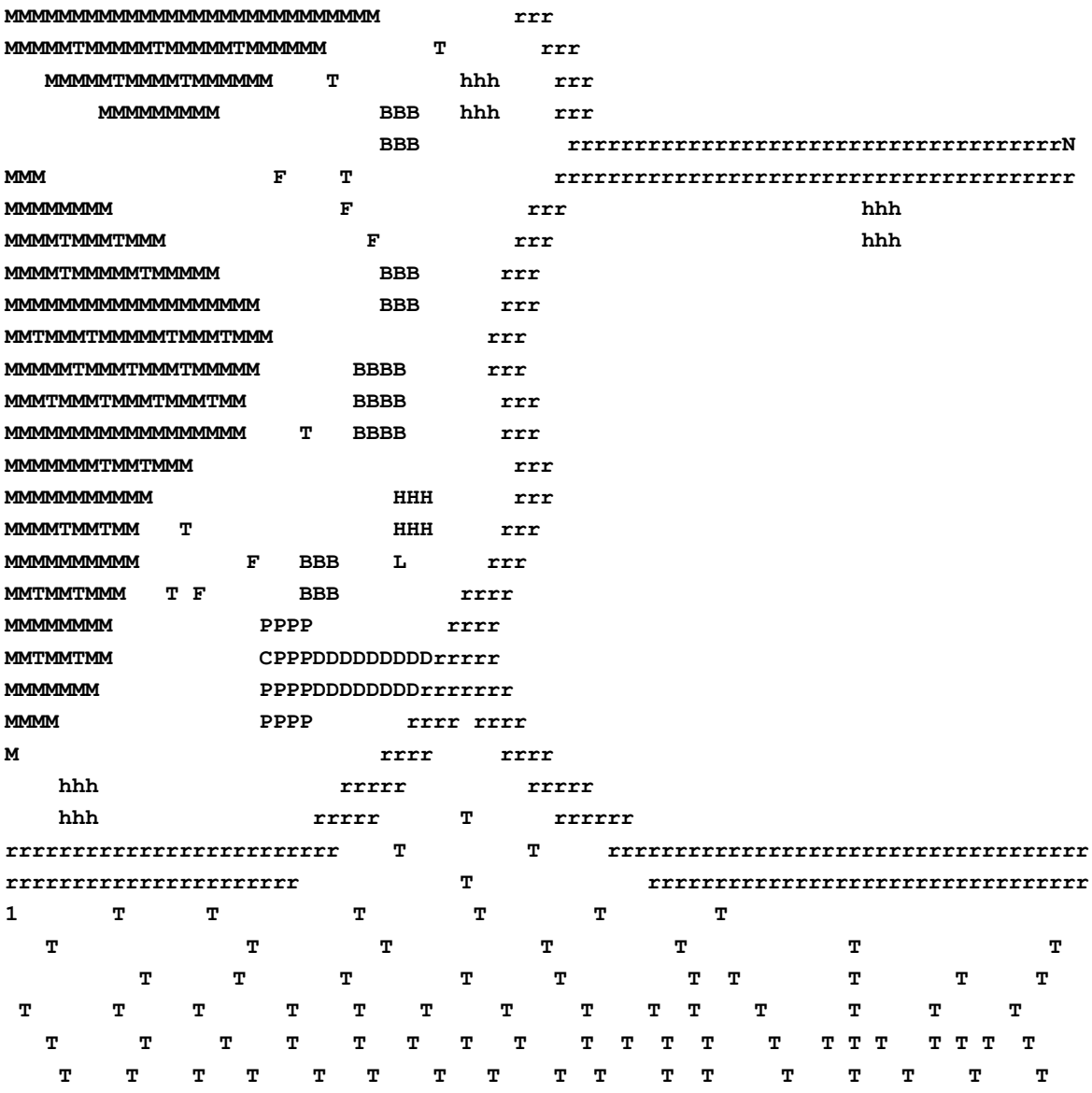
- Cyc: 185 events with ≥1 subevent (avg 1.7)
- FrameNet: 20 frames (0 subevents)
- Andrew Gordon's EPs: 768 EPs (avg 3.2 subevents)
- ThoughtTreasure: 100 scripts (avg **8.4** subevents)
- WordNet: no scripts but 427 synsets with outgoing entailment links (avg 1.06 subevents)

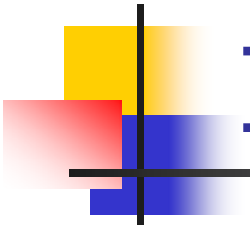
Grids in ThoughtTreasure

restaurant, bar, grocery-store, theater-ground-floor, theater-hall, TV-studio, city-apartment1, small-apartment-building-floor, small-apartment-building-ground-floor, city-apartment2, large-apartment-building-ground-floor, country-house-ground-floor, hotel-ground-floor, hotel-room-and-floor, city-street1, city-street2, city-street-and-park, country-area, subway-ticket-area, subway-platform1, subway-platform2, subway-platform3, subway-tracks, airport1, airport2, highway-map1, highway-map2, highway-map3


TVStudio grid

CountryArea grid





Inferences from grids

- Distance between objects
- Relative position of objects (left, right, front, back)
- Whether two actors can see or hear each other
- Whether there is a path from one location to another

Planning agents in ThoughtTreasure

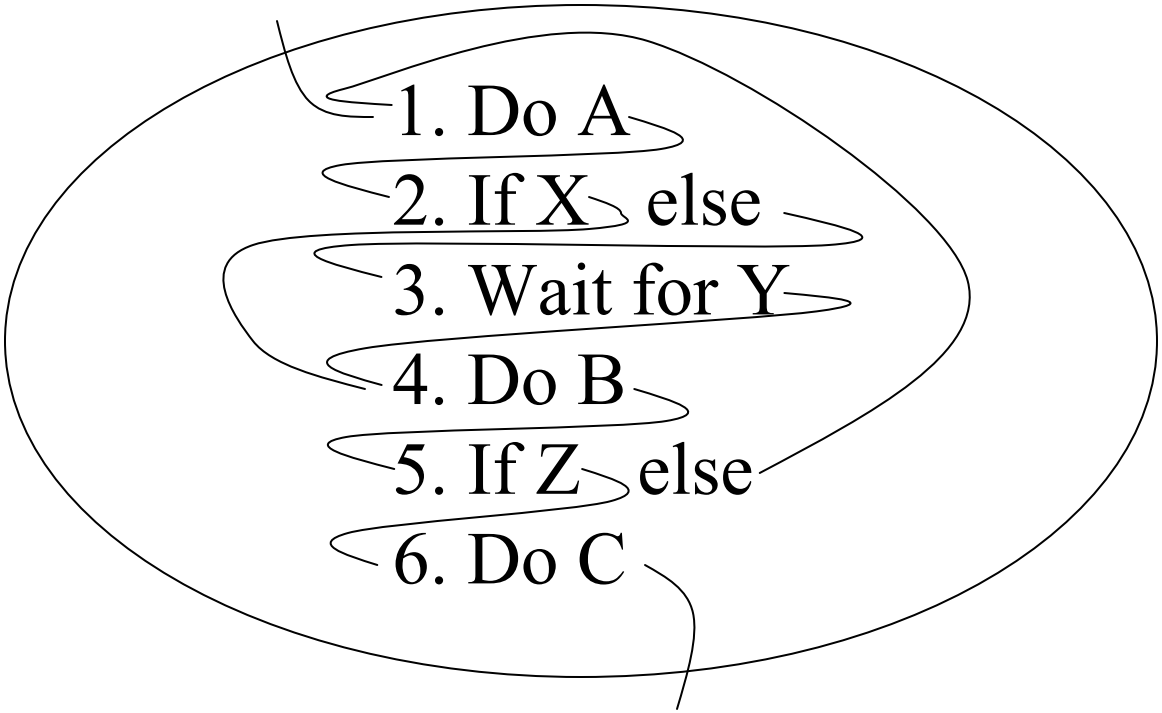
- GRASPER: Grasp, Release, Holding, Connect, ConnectedTo, Rub, Pour, SwitchX, FlipTo, KnobPosition, GestureHere, HandTo, ReceiveFrom
- CONTAINER: ActionOpen, ActionClose, Open, Closed, Inside
- MOVEMENT: MoveTo, MoveObject, SmallContainedObjectMove, HeldObjectMove, GrasperMove, ActorMove, LargeContainerMove
- TRANSPORTATION: NearAudible, NearReachable, NearGraspable, GridWalk, Sitting, Standing, Lying, Sit, Stand, Lie, Warp, Drive, GridDriveCar, MotorVehicleOn, MotorVehicleOff, Stay, Pack, Unpack
- COMMUNICATION: Mtrans, ObtainPermission, HandleProposal, Converse, Call, HandleCall, OffHook, OnHook, PickUp, HangUp, Dial
- MONEY: PayInPerson, PayCash, PayByCard, PayByCheck, CollectPayment, CollectCash
- INTERPERSONAL RELATIONS: MaintainFriends, Appointment
- ENTERTAINMENT: AttendPerformance, WorkBoxOffice, PurchaseTicket, WatchTV, TVSetOn, TVSetOff
- PERSONAL: Sleep, Shower, Dress, PutOn, Wearing, Strip, TakeOff

Device agents in ThoughtTreasure

- CAR: off, on, ignition
- TV: off, on, channel, antenna, plug
- TELEPHONE: hook, state, handset, dial, phone number, connection
- SHOWER: off, on, faucet, shower head, washing hair, shampoo

Planning agents (PAs)

Finite automata augmented with the ability to perform arbitrary computations



PhoneCall planning agent

```
call(A1, A2) :-
1:    T = FINDO(phone),
      H = FINDP(phone-handset, T),
      off-hook(H),
      WAIT FOR dialtone(T) AND GOTO 22
        OR WAIT 30 seconds AND GOTO 777,
22:   RETRIEVE phone-number-of(CLD =
                                  FINDO(phone NEAR A2),
                               N = number);
      dial(FINDP(right-hand, A1),
           FINDP(phone-dial, T), N),
      WAIT FOR busy-signal(T) AND GOTO 777
        OR WAIT FOR audible-ring(T, CLD) AND GOTO 4,
        OR WAIT 10 seconds AND GOTO 777
4:    WAIT FOR voice-connection(T, CLD) AND GOTO 5
        OR WAIT 30 seconds AND GOTO 777
```

PhoneCall planning agent

```
5:   WAIT FOR interjection-of-greeting(A3 = human, ?)
       AND GOTO 61
       OR WAIT 30 seconds AND GOTO 777
61:  ASSERT near-audible(A1, A3); IF A3 != A2 GOTO 990;
       calling-party-telephone-greeting(A1, A2),
62:  WAIT FOR mtrans(A1, A2) AND GOTO 7
       OR WAIT 5 seconds AND GOTO 990,
7:   WAIT FOR mtrans(A2, A1) AND GOTO 990
       OR WAIT 5 seconds AND GOTO 990,
777: on-hook(H) ON SUCCESS GOTO 1,
990: interjection-of-departure(A1, A3),
     WAIT FOR interjection-of-departure(A3, A1)
       OR WAIT 5 seconds,
     RETRACT near-audible(A1, A3);
       on-hook(H).
```

PhoneCall device agent

```
H = FINDP(phone-handset, T)
IF condition(T, W) and W < 0 { /* T broken */
  ASSERT idle(T)
} ELSE IF idle(T) {
  IF off-hook(H) ASSERT dialtone(T)
} ELSE IF dialtone(T) {
  IF on-hook(H) ASSERT idle(T) ...
} ELSE IF ringing(T, CLG = phone) {
  IF off-hook(H) {
    ASSERT voice-connection(CLG, T)
    ASSERT voice-connection(T, CLG)
  }
...
```

PurchaseTicket planning agent

```
purchase-ticket(A, P) :-
    dress(A, purchase-ticket),
    RETRIEVE building-of(P, BLDG);
      near-reachable(A, BLDG),
    near-reachable(A, FINDO(box-office)),
    near-reachable(A, FINDO(customer-side-of-counter)),
2:  interjection-of-greeting(A, B =
      FINDO(human NEAR employee-side-of-counter)),
    WAIT FOR may-I-help-you(B, A)
      OR WAIT 10 seconds AND GOTO 2,
5:  request(A, B, P),
6:  WAIT FOR I-am-sorry(B) AND GOTO 13
      OR WAIT FOR describe(B, A, TKT = ticket) AND GOTO 8
      OR WAIT 20 seconds AND GOTO 5,
8:  WAIT FOR propose-transaction(B, A, TKT, PRC = currency),
    IF TKT and PRC are OK accept(A, B) AND GOTO 10
    ELSE decline(A, B) AND GOTO 6,
10: pay-in-person(A, B, PRC),
    receive-from(A, B, TKT) ON FAILURE GOTO 13,
    ASSERT owner-of(TKT, A),
    post-sequence(A, B),
    SUCCESS,
13: post-sequence(A, B),
    FAILURE.
```

WorkBoxOffice planning agent

```
work-box-office(B, F) :-
     dress(B, work-box-office),
     near-reachable(B, F),
     TKTBOX = FINDO(ticket-box);
       near-reachable(B, FINDO(employee-side-of-counter)),
100: WAIT FOR attend(A = human, B) OR pre-sequence(A = human, B),
     may-I-help-you(B, A),
103: WAIT FOR request(A, B, R) AND GOTO 104
       OR WAIT FOR post-sequence(A, B) AND GOTO 110,
104: IF R ISA tod {
       current-time-sentence(B, A) ON COMPLETION GOTO 103
     } ELSE IF R ISA performance {
       GOTO 105
     } ELSE {
       interjection-of-noncomprehension(B, A)
       ON COMPLETION GOTO 103 }
105: find next available ticket TKT in TKTBOX for R;
       IF none { I-am-sorry(B, A) ON COMPLETION GOTO 103
       } ELSE { describe(B, A, TKT) ON COMPLETION GOTO 106 },
106: propose-transaction(B, A, TKT, TKT.price),
     WAIT FOR accept(A, B) AND GOTO 108
       OR WAIT FOR decline(A, B) AND GOTO 105
       OR WAIT 10 seconds AND GOTO 105,
108: collect-payment(B, A, TKT.price, FINDO(cash-register)),
109: hand-to(B, A, TKT),
110: post-sequence(B, A) ON COMPLETION GOTO 100.
```

Natural language processing: the basics

- Text agency: word, phrase, name, time and date expression, phone number, media object, product, price, end of sentence, communicon, email header, attribution, table
- Lexicon: part of speech, language, dialect, argument structure, selectional restriction, subcategorization restriction, inflection, prefix, suffix, derivational rule
- Syntactic component: syntactic parser, constituent, noun phrase, verb phrase, sentence, base rule, filter, barrier, transformation, compound tense, relative clause

Natural language processing: the basics

- **Semantic component:** semantic parser, case frame, semantic Cartesian product, theta marking, argument, adjunct, copula, relative clause, appositive, genitive, nominalization, conjunction, tense, aspect, anaphoric parser, antecedent, salience, feature unification, article, intension, extension, c-command, deixis, speaker, listener, story time, now
- **Generator:** English, French, indicative, subjunctive, generation advice, unit of measure, value range names
- **Question answering:** Yes-No question, question-word question, location, time, temporal relation, degree, quantity, description, means, reason, explanation, clarification, narrowing down

A lexical entry definition

```
=pour-on//pour* on+.Véz/
|r1=human|r2=physical-object|
r3=physical-object|

+ = takes indirect object
V = verb
é = takes direct object
z = English
```

ú = subject assigned to slot 2
ü = subject assigned to slot 3
è = object assigned to slot 1
é = object assigned to slot 2
ë = object assigned to slot 3
÷ = indicative *(that) he goes*
O = subjunctive *(that) he go*
Ï = infinitive *(for him) to go*
± = present participle *(him) going*
...

Semantic parsing

The American who daydreams, ate.

```
[preterit-indicative
 [ingest
  [such-that
   [definite-article human]
   [present-indicative
    [daydream human na]]
   [nationality-of human US]]
  food]]
```

Semantic parsing

I want to buy a Fiat Spyder.

```
[present-indicative
 [active-goal
  subject-pronoun
  [buy subject-pronoun na
       Fiat-Spider na]]]

[present-indicative
 [active-goal
  Jim
  [buy Jim na Fiat-Spider na]]]
```

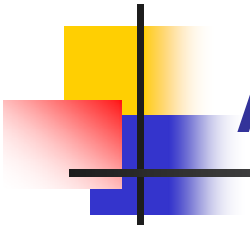
Semantic parsing

How are you?

```
[how-are-you Jim TT]
```

What is your address?

```
[present-indicative
 [email-address-of TT
  object-interrogative-pronoun]]
```



Anaphoric parsing

- Resolves *I, you* based on speaker, listener
- Resolves *him, her, they* based on previously mentioned actors
- Resolves *the X* based on objects of type *X* previously mentioned or spatially near previously mentioned actors
- Resolves *the red X* or *the X that is red* based on red *X*'s

He poured Pert Plus on his hair.

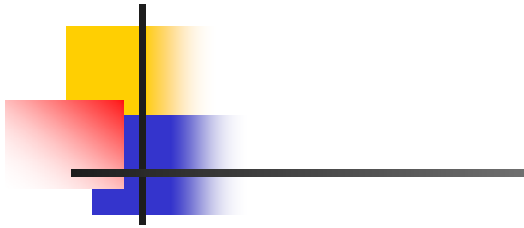
```
[preterit-indicative
 [pour
  [such-that
   grasper
    [of grasper subject-pronoun]]
  Pert-Plus
  [possessive-determiner hair]]]

[preterit-indicative
 [pour Jim-left-hand Pert-Plus Jim-head-hair]]
```

Implementation of a UA

```
void UA_Emotion_FortunesOfOthers(Actor *ac, Ts *ts, Obj *a, Obj *in,
                                 Obj *other, Float weight,
                                 Obj *other_emot_class)
{
  int           found;
  Float         weight1;
  Obj           *other_emot_class1;
  ObjList       *causes, *objs, *atts, *p, *q;

  /* Relate <a's emotion to <a's attitudes. */
  if (0.0 != (weight1 = UA_FriendAttitude(ts, a, other, 1, &atts))) {
    if (FloatSign(weight1) == FloatSign(weight)) {
    /* The input emotion agrees with known attitudes. */
      ContextSetRSN(ac-cx, RELEVANCE_TOTAL, SENSE_TOTAL, NOVELTY_HALF);
      ContextAddMakeSenseReasons(ac-cx, atts);
    } else {
    /* The input emotion disagrees with known attitudes. */
      ContextSetRSN(ac-cx, RELEVANCE_TOTAL, SENSE_LITTLE, NOVELTY_TOTAL);
      ContextAddNotMakeSenseReasons(ac-cx, atts);
    }
  } else {
    /* Attitude of <a toward <other is unknown. */
    ContextSetRSN(ac-cx, RELEVANCE_TOTAL, SENSE_MOSTLY, NOVELTY_MOSTLY);
    UA_Infer(ac-cx-dc, ac-cx, ts,
             L(N("like-human"), a, other, NumberToObj(weight), E), in);
  }
...
```



More stories handled by ThoughtTreasure

GROCER and SPACE UAs

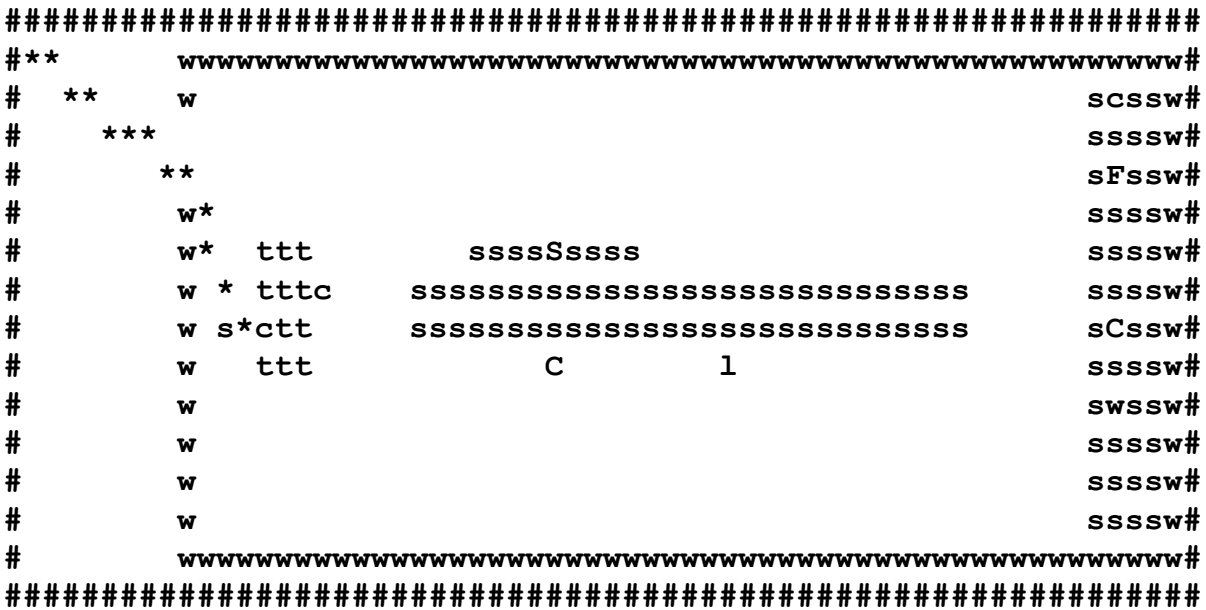
Jenny Powell was a grocer.

spin GROCER PA to AWAIT-CUSTOMER

Jenny walks to checkout counter

At seven am she stepped out into the street.

Jenny walks to street



Question answering

Q: Where was Jenny's left foot?
A: Her left foot was in the corner grocery.

Q: What salamis was she near?
A: She was near Danish salami.

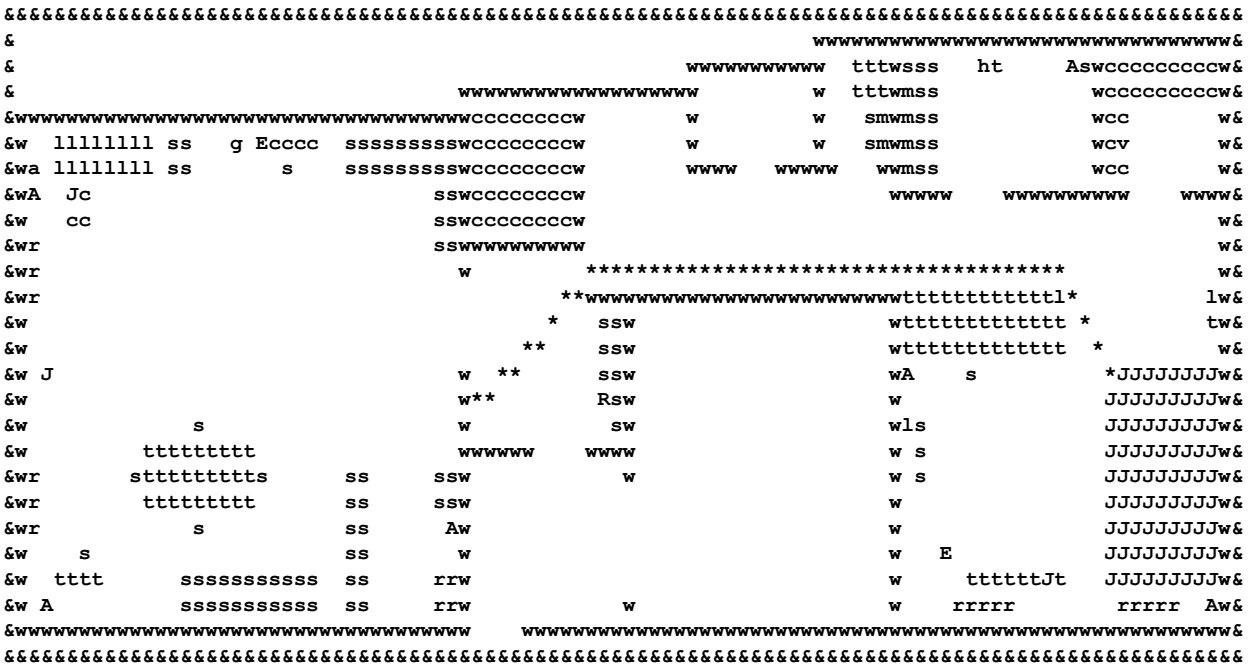
Q: When did she step out into the street?
A: She walked to the street at seven am.

SLEEP and SHOWER UAs

Jim was sleeping.

spin SLEEP PA to ASLEEP

Jim lies down in bed



He woke up.

spin SLEEP PA to AWAKE

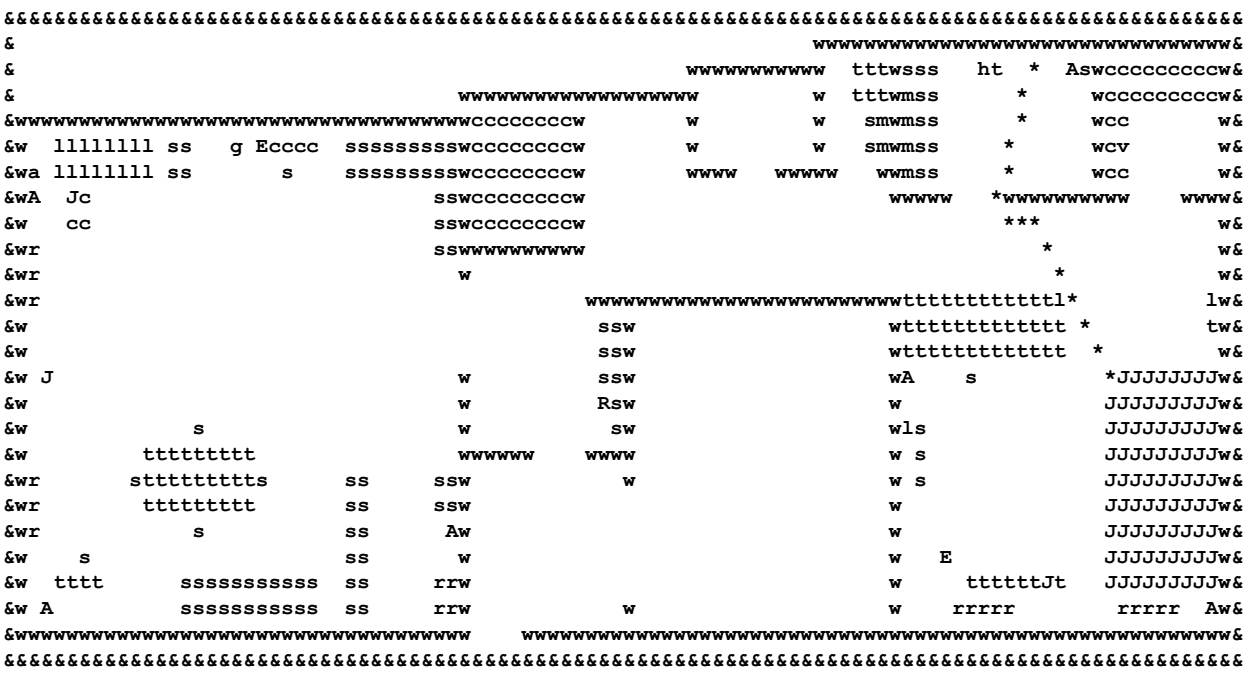
He poured Pert Plus on his hair.

spin SHOWER PA to READY-TO-LATHER

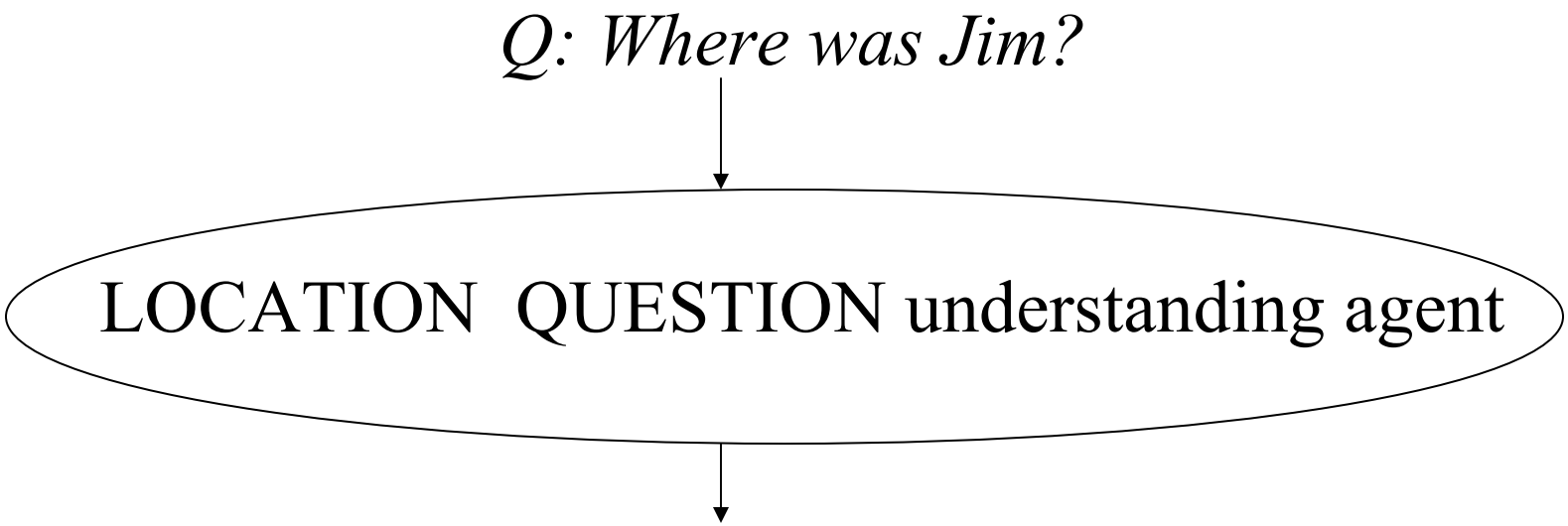
Jim walks to shower

Jim turns on shower

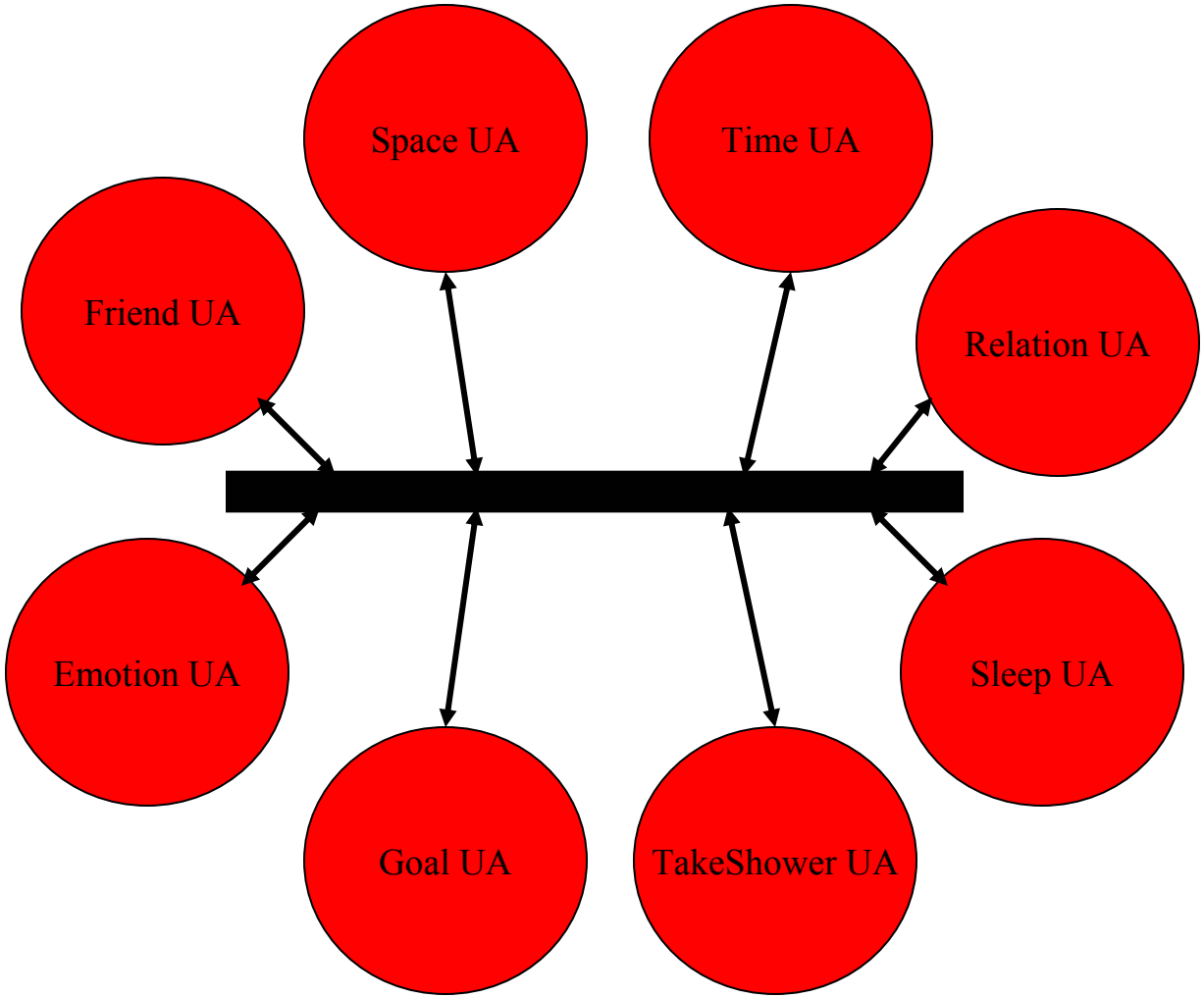
Jim pours shampoo on hair



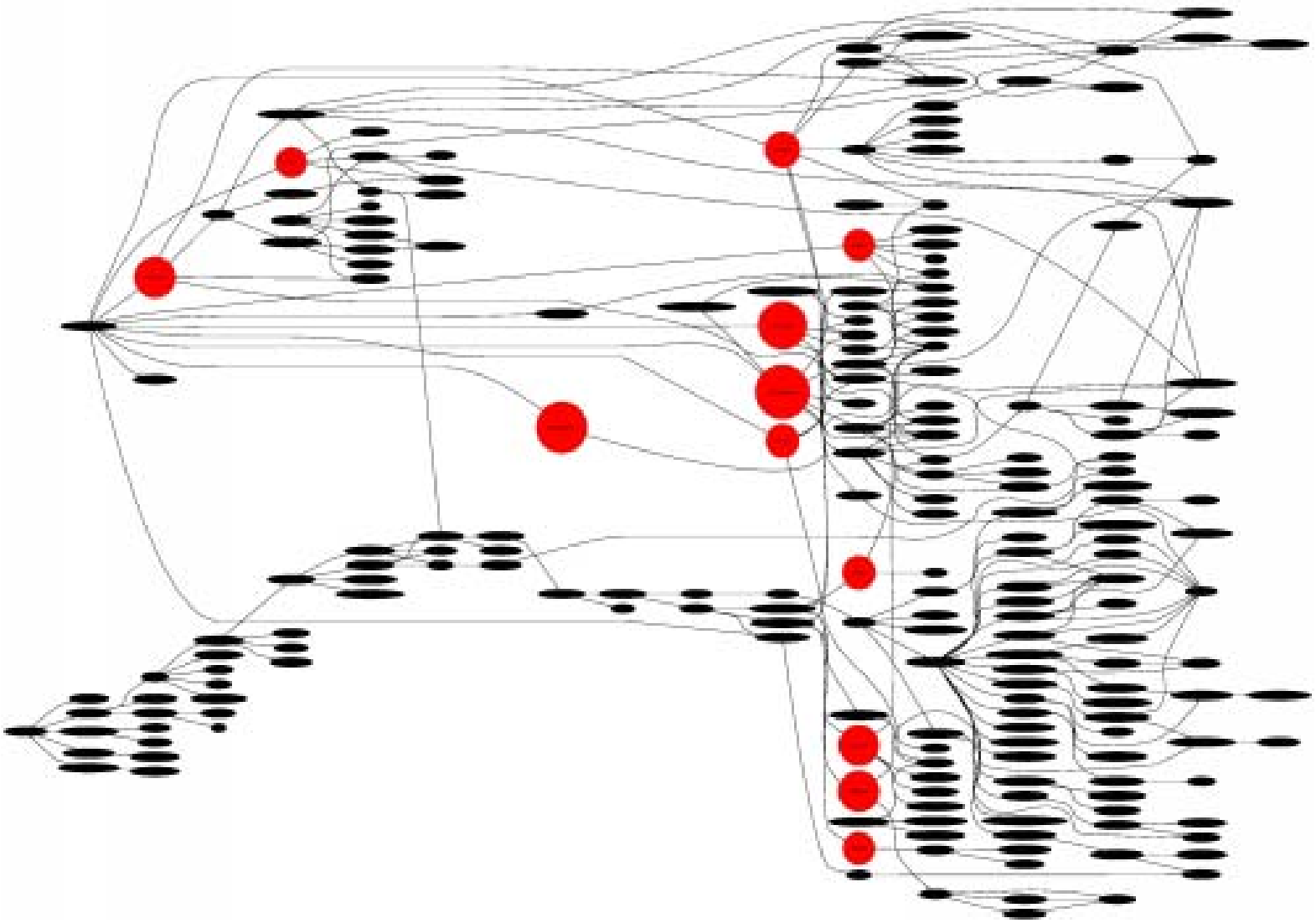
Question answering UAs



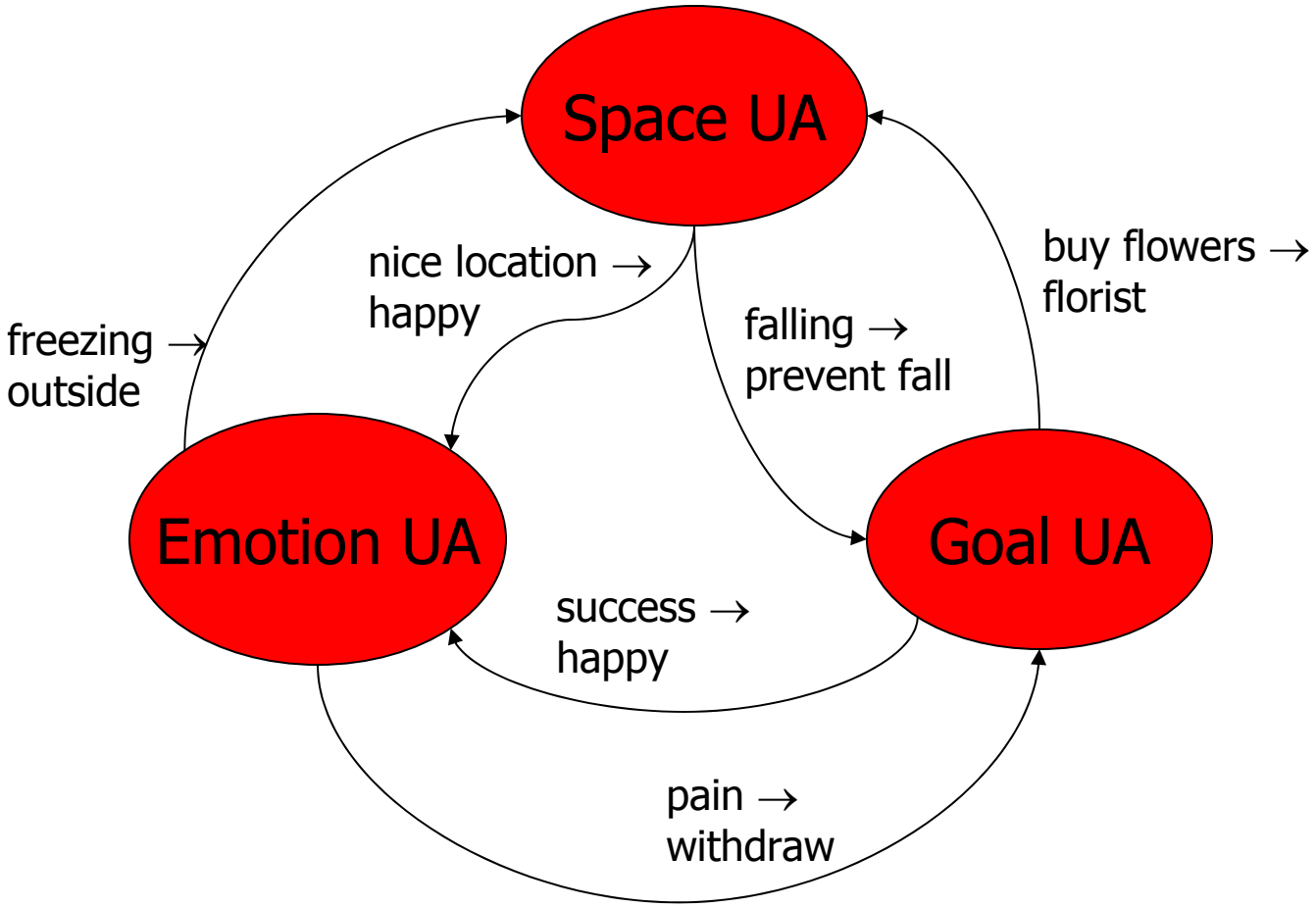
Understanding agency: Image

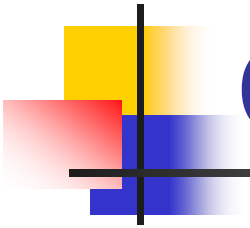


Understanding agency: Reality



Complex agent dependencies





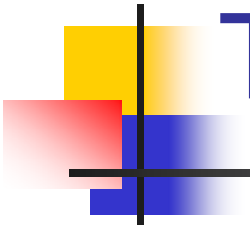
Complex updates

Jim went to sleep.

1. Jim walks to bed.
2. Jim lies down.
3. Jim falls asleep.

Many possible language inputs

Mary is sleeping.
Mary is lying awake in her bed.
Mary was lying asleep in her bed.
Mary was asleep and Jim did not want to wake her.
At ten in the morning, Mary was still asleep.
Mary had only slept a few hours.
…



ThoughtTreasure wish list

- Better concept and lexical entry coverage
- Better coverage of stereotypical locations
- Better script coverage
- Better coverage of typical object properties
- Script recognition
- Script-based word sense disambiguation
- Dynamic location generation
- English annotation of knowledge base
- Graphical tools for commonsense knowledge entry
- Graphical display of simulation
- Compound noun understanding
- Question-based understanding
- Metaplanning