Semantic Role Labeling

Introduction

Many slides adapted from Dan Jurafsky

Semantic Role Labeling

Who　　did *what* to *whom*　　at *where?*

The police officer detained the suspect at the scene of the crime

Agent　　　Predicate　　Theme　　　　　Location
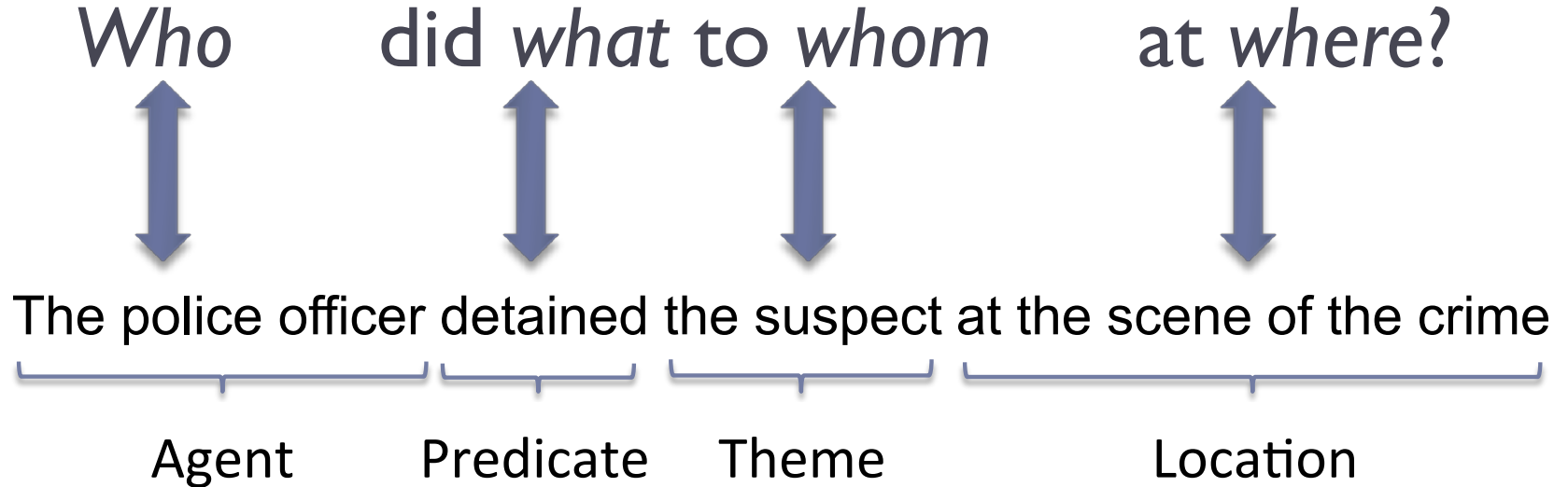
Can we figure out that these have the same meaning?

XYZ corporation **bought** the stock.

They **sold** the stock to XYZ corporation.

The stock was **bought** by XYZ corporation.

The **purchase** of the stock by XYZ corporation…

The stock **purchase** by XYZ corporation…

A Shallow Semantic Representation: Semantic Roles

Predicates (bought, sold, purchase) represent an **event**

semantic roles express the abstract role that arguments of a predicate can take in the event

More specific   More general

⟵————————————————————————————⟶

buyer   **agent**   **agent**

Semantic Role Labeling

Semantic Roles

Getting to semantic roles

Neo-Davidsonian event representation:

Sasha broke the window

Pat opened the door

$$\exists e, x, y \, Breaking(e) \wedge Breaker(e, Sasha)$$
$$\wedge BrokenThing(e, y) \wedge Window(y)$$
$$\exists e, x, y \, Opening(e) \wedge Opener(e, Pat)$$
$$\wedge OpenedThing(e, y) \wedge Door(y)$$

Subjects of break and open: **Breaker** and **Opener**

Deep roles specific to each event (breaking, opening)

Hard to reason about them for NLU applications like QA

Thematic roles

- **Breaker** and **Opener** have something in common!
  - Volitional actors
  - Often animate
  - Direct causal responsibility for their events
- Thematic roles are a way to capture this semantic commonality between *Breakers* and *Eaters*.
- They are both AGENTS.
- The *BrokenThing* and *OpenedThing*, are THEMES.
  - prototypically inanimate objects affected in some way by the action

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Thematic roles

- One of the oldest linguistic models
  - Indian grammarian Panini between the 7th and 4th centuries BCE
- Modern formulation from Fillmore (1966,1968), Gruber (1965)
  - Fillmore influenced by Lucien Tesnière's (1959) *Éléments de Syntaxe Structurale,* the book that introduced dependency grammar
  - Fillmore first referred to roles as *actants* (Fillmore, 1966) but switched to the term *case*

Thematic roles

- A typical set:

Thematic Role	Definition	Example
AGENT	The volitional causer of an event	*The waiter* spilled the soup.
EXPERIENCER	The experiencer of an event	*John* has a headache.
FORCE	The non-volitional causer of the event	*The wind* blows debris from the mall into our yards.
THEME	The participant most directly affected by an event	Only after Benjamin Franklin broke *the ice*...
RESULT	The end product of an event	The city built a *regulation-size baseball diamond*...
CONTENT	The proposition or content of a propositional event	Mona asked *"You met Mary Ann at a supermarket?"*
INSTRUMENT	An instrument used in an event	He poached catfish, stunning them *with a shocking device*...
BENEFICIARY	The beneficiary of an event	Whenever Ann Callahan makes hotel reservations *for her boss*...
SOURCE	The origin of the object of a transfer event	I flew in *from Boston*.
GOAL	The destination of an object of a transfer event	I drove *to Portland*.

Thematic grid, case frame, θ-grid

Example usages of "break"

John   broke the window.
AGENT   THEME

John   broke the window with a rock.
AGENT   THEME   INSTRUMENT

The rock   broke the window.
INSTRUMENT   THEME

The window broke.
THEME

The window was broken by John.
THEME   AGENT

thematic grid, case frame, θ-grid
Break:
  AGENT, THEME, INSTRUMENT.

  Some realizations:

AGENT/Subject, THEME/Object
AGENT/Subject, THEME/Object, INSTRUMENT/PP$_{with}$
INSTRUMENT/Subject, THEME/Object
THEME/Subject

Diathesis alternations (or verb alternation)

Doris gave the book to Cary.
AGENT   THEME   BENEFICIARY

Doris gave Cary the book.
AGENT BENEFICIARY THEME

Break: AGENT, INSTRUMENT, or THEME as subject

Give: THEME and GOAL in either order

Dative alternation: particular semantic classes of verbs, "verbs of future having" (*advance, allocate, offer, owe*), "send verbs" (*forward, hand, mail*), "verbs of throwing" (*kick, pass, throw*), etc.

Levin (1993): 47 semantic classes ("**Levin classes**") for 3100 English verbs and alternations. In online resource VerbNet.

Problems with Thematic Roles

Hard to create standard set of roles or formally define them

Often roles need to be fragmented to be defined.

Levin and Rappaport Hovav (2015): two kinds of INSTRUMENTS

intermediary instruments that can appear as subjects

The cook opened the jar with the new gadget.

The new gadget opened the jar.

enabling instruments that cannot

Shelly ate the sliced banana with a fork.

*The fork ate the sliced banana.

Alternatives to thematic roles

1. **Fewer roles**: generalized semantic roles, defined as prototypes (Dowty 1991)

   PROTO-AGENT

   PROTO-PATIENT

   PropBank

2. **More roles**: Define roles specific to a group of predicates

   FrameNet

Semantic Role Labeling

The Proposition Bank (PropBank)

PropBank

- Palmer, Martha, Daniel Gildea, and Paul Kingsbury. 2005. The Proposition Bank: An Annotated Corpus of Semantic Roles. *Computational Linguistics*, 31(1):71–106

PropBank Roles

Following Dowty 1991

Proto-Agent
- Volitional involvement in event or state
- Sentience (and/or perception)
- Causes an event or change of state in another participant
- Movement (relative to position of another participant)

Proto-Patient
- Undergoes change of state
- Causally affected by another participant
- Stationary relative to movement of another participant

PropBank Roles

- Following Dowty 1991
  - Role definitions determined verb by verb, with respect to the other roles
  - Semantic roles in PropBank are thus verb-sense specific.
- Each verb sense has numbered argument: Arg0, Arg1, Arg2,…

  Arg0: PROTO-AGENT

  Arg1: PROTO-PATIENT

  Arg2: usually: benefactive, instrument, attribute, or end state

  Arg3: usually: start point, benefactive, instrument, or attribute

  Arg4 the end point

(Arg2-Arg5 are not really that consistent, causes a problem for labeling)

PropBank Frame Files

agree.01

Arg0: Agreer
Arg1: Proposition
Arg2: Other entity agreeing

Ex1: [$_{Arg0}$ The group] *agreed* [$_{Arg1}$ it wouldn't make an offer].
Ex2: [$_{ArgM-TMP}$ Usually] [$_{Arg0}$ John] *agrees* [$_{Arg2}$ with Mary] [$_{Arg1}$ on everything].

fall.01

Arg1: Logical subject, patient, thing falling
Arg2: Extent, amount fallen
Arg3: start point
Arg4: end point, end state of arg1
Ex1: [$_{Arg1}$ Sales] *fell* [$_{Arg4}$ to $25 million] [$_{Arg3}$ from $27 million].
Ex2: [$_{Arg1}$ The average junk bond] *fell* [$_{Arg2}$ by 4.2%].

Advantage of a ProbBank Labeling

increase.01 "go up incrementally"
Arg0: causer of increase
Arg1: thing increasing
Arg2: amount increased by, EXT, or MNR
Arg3: start point
Arg4: end point

This would allow us to see the commonalities in these 3 sentences:

[$_{Arg0}$ Big Fruit Co.] increased [$_{Arg1}$ the price of bananas].
[$_{Arg1}$ The price of bananas] was increased again [$_{Arg0}$ by Big Fruit Co.]
[$_{Arg1}$ The price of bananas] increased [$_{Arg2}$ 5%].
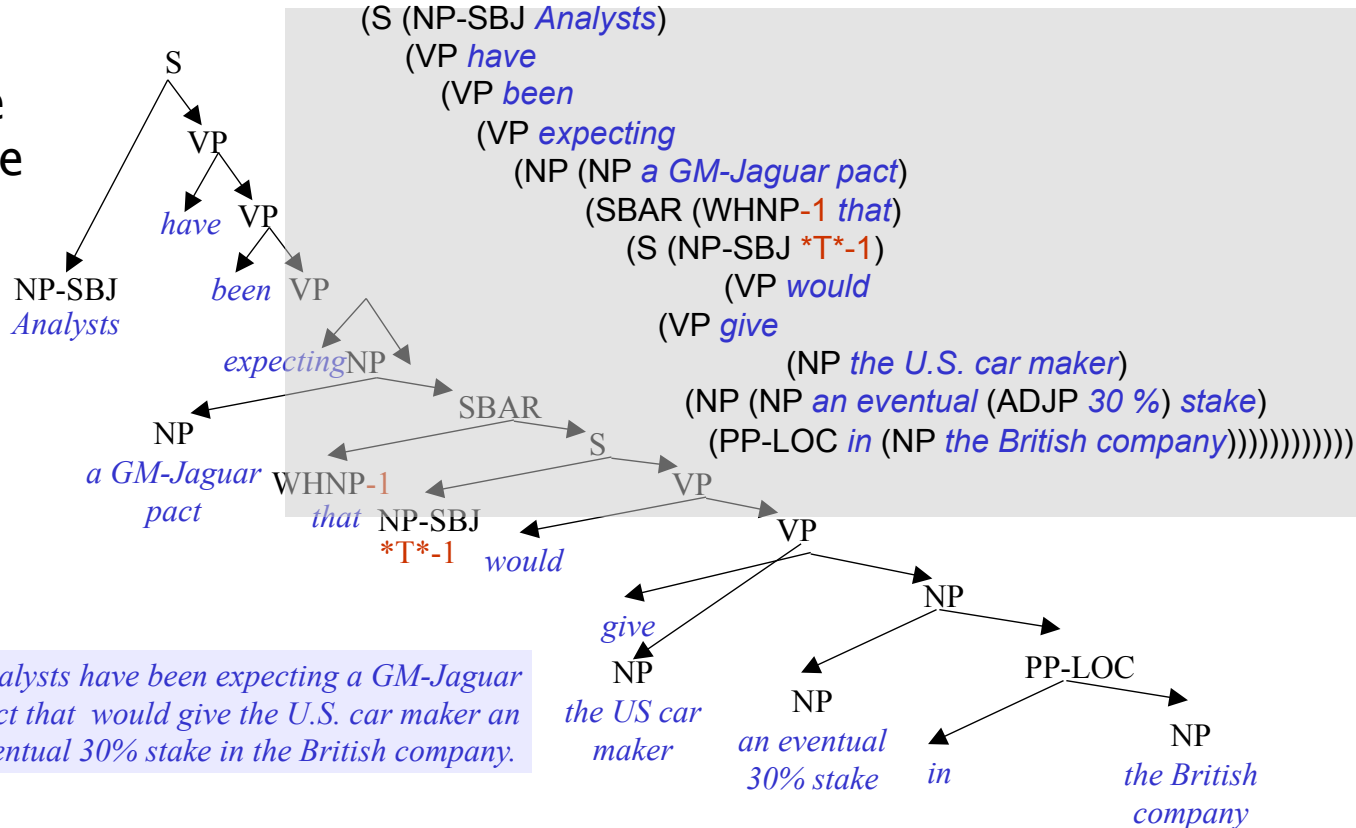
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Modifiers or adjuncts of the predicate: Arg-M

ArgM-TMP	when?	yesterday evening, now
LOC	where?	at the museum, in San Francisco
DIR	where to/from?	down, to Bangkok
MNR	how?	clearly, with much enthusiasm
PRP/CAU	why?	because ... , in response to the ruling
REC		themselves, each other
ADV	miscellaneous	
PRD	secondary predication	...ate the meat raw

PropBanking a Sentence

Martha Palmer 2013

A sample
parse tree

```
(S (NP-SBJ Analysts)
  (VP have
    (VP been
      (VP expecting
        (NP (NP a GM-Jaguar pact)
          (SBAR (WHNP-1 that)
            (S (NP-SBJ *T*-1)
              (VP would
                (VP give
                  (NP the U.S. car maker)
                  (NP (NP an eventual (ADJP 30 %) stake)
                  (PP-LOC in (NP the British company))))))))))))))
```

S

VP

have   VP

NP-SBJ   been   VP
Analysts

expecting NP

NP   SBAR
a GM-Jaguar WHNP-1   S
pact   that   NP-SBJ   VP
                     T-1   would   VP

give   NP

NP   NP   PP-LOC
the US car
maker   an eventual
             30% stake   in   NP
                                    the British
                                    company

*Analysts have been expecting a GM-Jaguar
pact that would give the U.S. car maker an
eventual 30% stake in the British company.*

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The same parse tree PropBanked

Martha Palmer 2013

have been expecting

Arg0   Arg1

Analysts   *a GM-Jaguar pact*

Arg0

that would give   Arg1

T-1   *an eventual 30% stake in the British company*

Arg2

the US car maker

```
(S Arg0 (NP-SBJ Analysts)
    (VP have
        (VP been
            (VP expecting
                Arg1 (NP (NP a GM-Jaguar pact)
                    (SBAR (WHNP-1 that)
                        (S Arg0 (NP-SBJ *T*-1)
                            (VP would
                                (VP give
                                    Arg2 (NP the U.S. car maker)
                                    Arg1 (NP (NP an eventual (ADJP 30 %) stake)
                                        (PP-LOC in (NP the British
company)))))))))))))
```
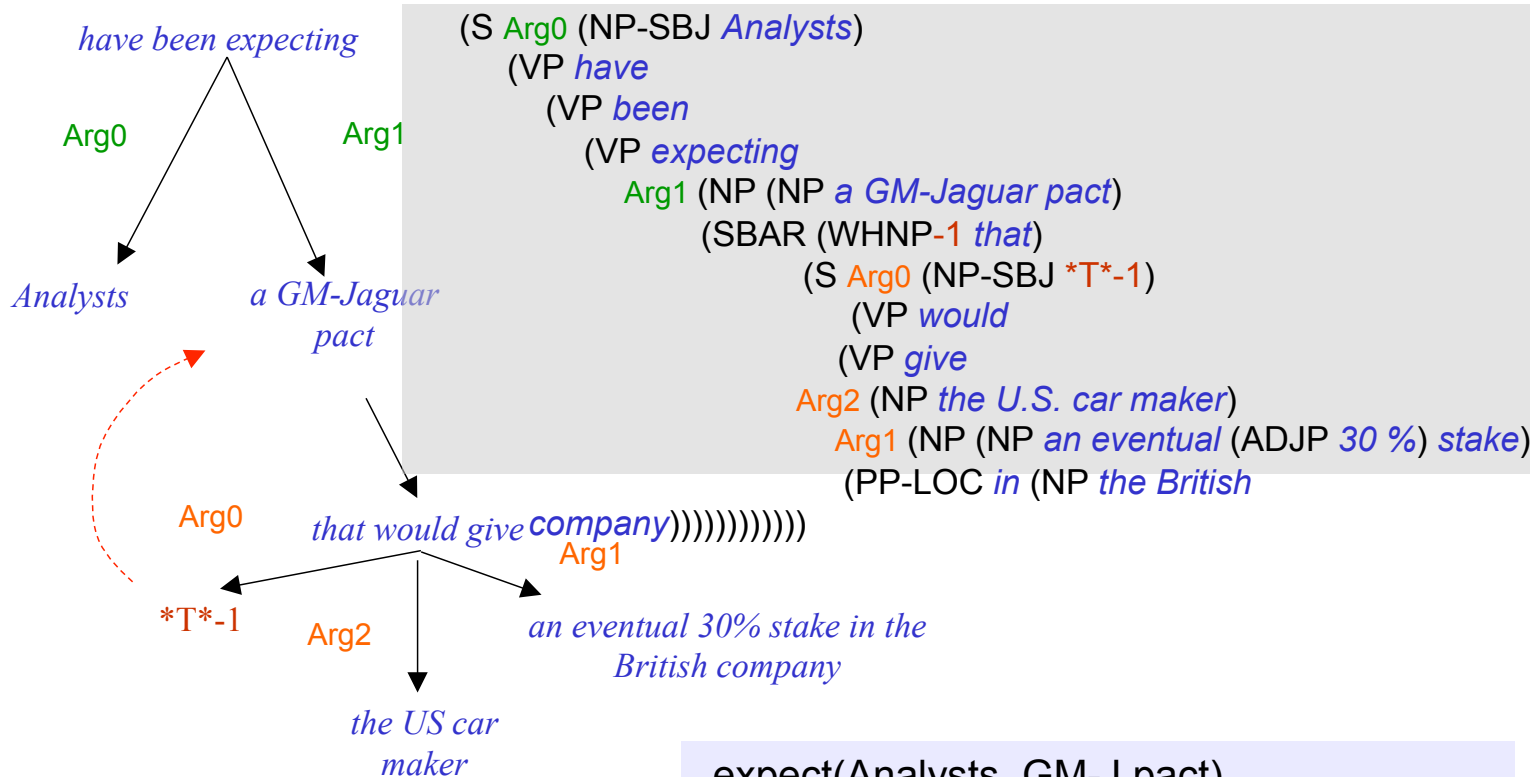
expect(Analysts, GM-J pact)
give(GM-J pact, US car maker, 30% stake)

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Annotated PropBank Data

2013 Verb Frames Coverage
Count of word sense (lexical units)

- Penn English TreeBank,
  OntoNotes 5.0.
  - Total ~2 million words
- Penn Chinese TreeBank
- Hindi/Urdu PropBank
- Arabic PropBank

Language	*Final Count*
English	**10,615***
Chinese	**24, 642**
Arabic	**7,015**

From Martha Palmer 2013 Tutorial

Plus nouns and light verbs

Example Noun: *Decision*

▸ Roleset: Arg0: decider, Arg1: decision…

▸ "…[your$_{ARG0}$] [decision$_{REL}$]
[to say look I don't want to go through this anymore$_{ARG1}$]"

Example within an LVC: *Make a decision*

▸ "…[the President$_{ARG0}$] [made$_{REL\text{-}LVB}$]
the [fundamentally correct$_{ARGM\text{-}ADJ}$]
[decision$_{REL}$] [to get on offense$_{ARG1}$]"

Slight from Palmer 2013

Semantic Role Labeling

FrameNet

Capturing descriptions of the same event by different nouns/verbs

[Arg1 The price of bananas] increased [Arg2 5%].

[Arg1 The price of bananas] rose [Arg2 5%].

There has been a [Arg2 5%] rise [Arg1 in the price of bananas].

FrameNet

- Baker et al. 1998, Fillmore et al. 2003, Fillmore and Baker 2009, Ruppenhofer et al. 2006

- Roles in PropBank are specific to a verb

- Role in FrameNet are specific to a **frame: a** background knowledge structure that defines a set of frame-specific semantic roles, called **frame elements**,
  - includes a set of predicates that use these roles
  - each word evokes a frame and profiles some aspect of the frame

The "Change position on a scale" Frame

This frame consists of words that indicate the change of an ITEM's position on a scale (the ATTRIBUTE) from a starting point (INITIAL VALUE) to an end point (FINAL VALUE)

[ITEM Oil] *rose* [ATTRIBUTE in price] [DIFFERENCE by 2%].

[ITEM It] has *increased* [FINAL_STATE to having them 1 day a month].

[ITEM Microsoft shares] *fell* [FINAL_VALUE to 7 5/8].

[ITEM Colon cancer incidence] *fell* [DIFFERENCE by 50%] [GROUP among men].

a steady *increase* [INITIAL_VALUE from 9.5] [FINAL_VALUE to 14.3] [ITEM in dividends]

a [DIFFERENCE 5%] [ITEM dividend] *increase...*

The "Change position on a scale" Frame

VERBS: dwindle move soar escalation shift
advance edge mushroom swell explosion tumble
climb explode plummet swing fall
decline fall reach triple fluctuation **ADVERBS:**
decrease fluctuate rise tumble gain increasingly
diminish gain rocket growth
dip grow shift **NOUNS:** hike
double increase skyrocket decline increase
drop jump slide decrease rise

The "Change position on a scale" Frame

Core Roles	
ATTRIBUTE	The ATTRIBUTE is a scalar property that the ITEM possesses.
DIFFERENCE	The distance by which an ITEM changes its position on the scale.
FINAL_STATE	A description that presents the ITEM's state after the change in the ATTRIBUTE value as an independent predication.
FINAL_VALUE	The position on the scale where the ITEM ends up.
INITIAL_STATE	A description that presents the ITEM's state before the change in the ATTRIBUTE's value as an independent predication.
INITIAL_VALUE	The initial position on the scale from which the ITEM moves away.
ITEM	The entity that has a position on the scale.
VALUE_RANGE	A portion of the scale, typically identified by its end points, along which the values of the ATTRIBUTE fluctuate.
Some Non-Core Roles	
DURATION	The length of time over which the change takes place.
SPEED	The rate of change of the VALUE.
GROUP	The GROUP in which an ITEM changes the value of an ATTRIBUTE in a specified way.

Relation between frames

Inherits from:
Is Inherited by:
Perspective on:
Is Perspectivized in:
Uses:
Is Used by:
Subframe of:
Has Subframe(s):
Precedes:
Is Preceded by:
Is Inchoative of:
Is Causative of:

Relation between frames

"cause change position on a scale"

Is Causative of: Change_position_on_a_scale

Adds an agent Role

[$_{\text{AGENT}}$ They] *raised* [$_{\text{ITEM}}$ the price of their soda] [$_{\text{DIFFERENCE}}$ by 2%].

- *add.v, crank.v, curtail.v, cut.n, cut.v, decrease.v, development.n, diminish.v, double.v, drop.v, enhance.v, growth.n, increase.v, knock down.v, lower.v, move.v, promote.v, push.n, push.v, raise.v, reduce.v, reduction.n, slash.v, step up.v, swell.v*

Schematic of Frame Semantics

Figure from Das et al (2014)
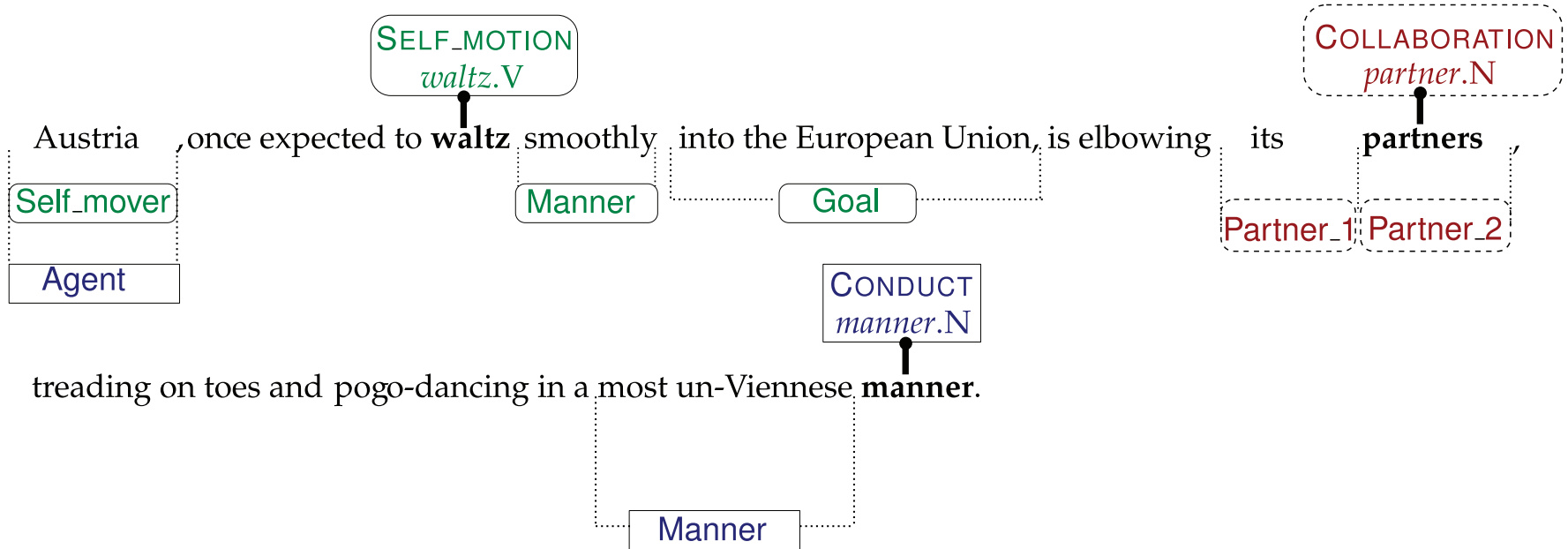
FrameNet Complexity

But there still are n't enough ringers to ring more than six of the eight bells .   *Frame*   *LU*

N_m	**NOISE_MAKERS**	*bell.n*
Sound_maker	**CAUSE_TO_MAKE_NOISE**	*ring.v*
Enabled_situation	**SUFFICIENCY**	*enough.a*
Entity	**EXISTENCE**	*there be.v*

Agent
Item

From Das et al. 2010

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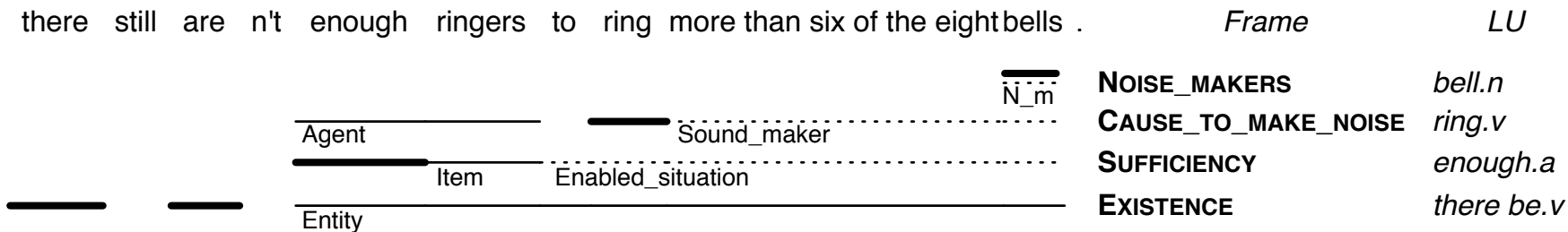
FrameNet and PropBank representations

(a)
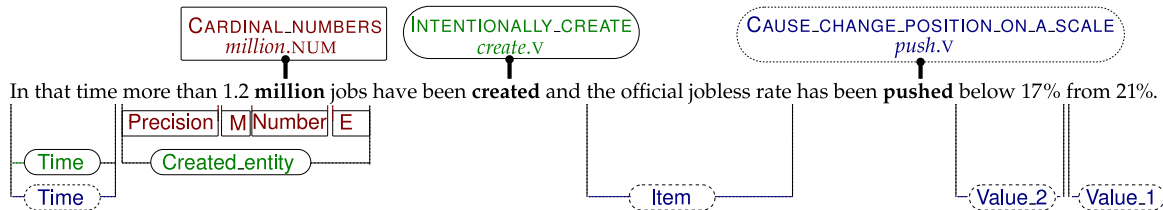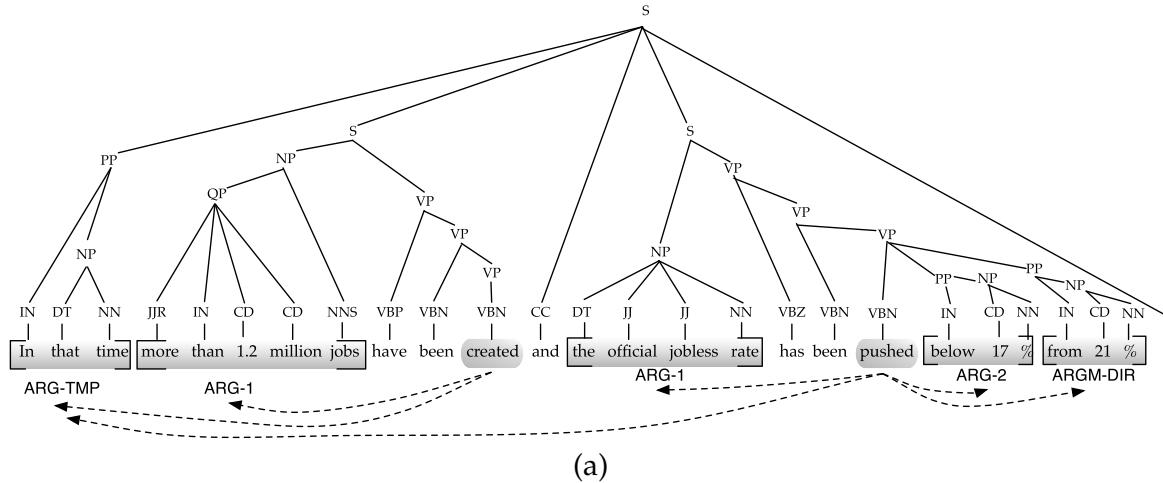
Semantic Role Labeling

Semantic Role Labeling Algorithm

Semantic role labeling (SRL)

- The task of finding the semantic roles of each argument of each predicate in a sentence.

- FrameNet versus PropBank:

[You]   can't   [blame]   [the program]   [for being unable to identify it]
COGNIZER   TARGET   EVALUEE   REASON

[The San Francisco Examiner]   issued   [a special edition]   [yesterday]
ARG0   TARGET   ARG1   ARGM-TMP

History

- Semantic roles as a intermediate semantics, used early in
  - machine translation (Wilks, 1973)
  - question-answering (Hendrix et al., 1973)
  - spoken-language understanding (Nash-Webber, 1975)
  - dialogue systems (Bobrow et al., 1977)

- Early SRL systems

  Simmons 1973, Marcus 1980:

  - parser followed by hand-written rules for each verb

  - dictionaries with verb-specific case frames (Levin 1977)

Why Semantic Role Labeling

- A useful shallow semantic representation

- Improves NLP tasks like:

  - question answering

    Shen and Lapata 2007, Surdeanu et al. 2011

  - machine translation

    Liu and Gildea 2010, Lo et al. 2013

A simple modern algorithm

function SEMANTICROLELABEL(*words*) **returns** labeled tree

    parse ← PARSE(*words*)
    for each *predicate* **in** *parse* **do**
        for each *node* **in** *parse* **do**
            featurevector ← EXTRACTFEATURES(*node*, *predicate*, *parse*)
            CLASSIFYNODE(*node*, *featurevector*, *parse*)

How do we decide what is a predicate

- If we're just doing PropBank verbs
  - Choose all verbs
  - Possibly removing light verbs (from a list)
- If we're doing FrameNet (verbs, nouns, adjectives)
  - Choose every word that was labeled as a target in training data

Semantic Role Labeling

S

NP-SBJ = *ARG0*

DT — The
NNP — San
NNP — Francisco
NNP — Examiner

VP

VBD = *TARGET* — issued

NP = *ARG1*

DT — a
JJ — special
NN — edition

PP-TMP = *ARGM-TMP*

IN — around

NP

NN — noon
NP-TMP — yesterday
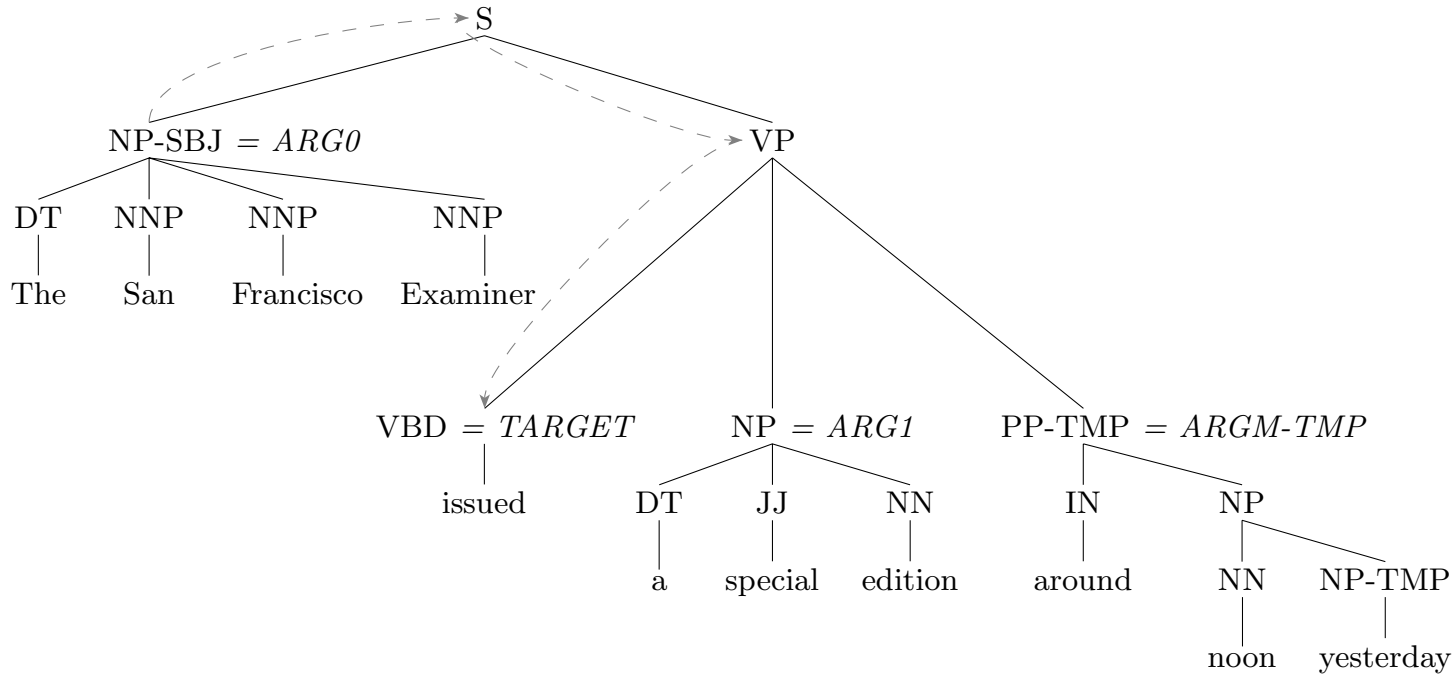
Features
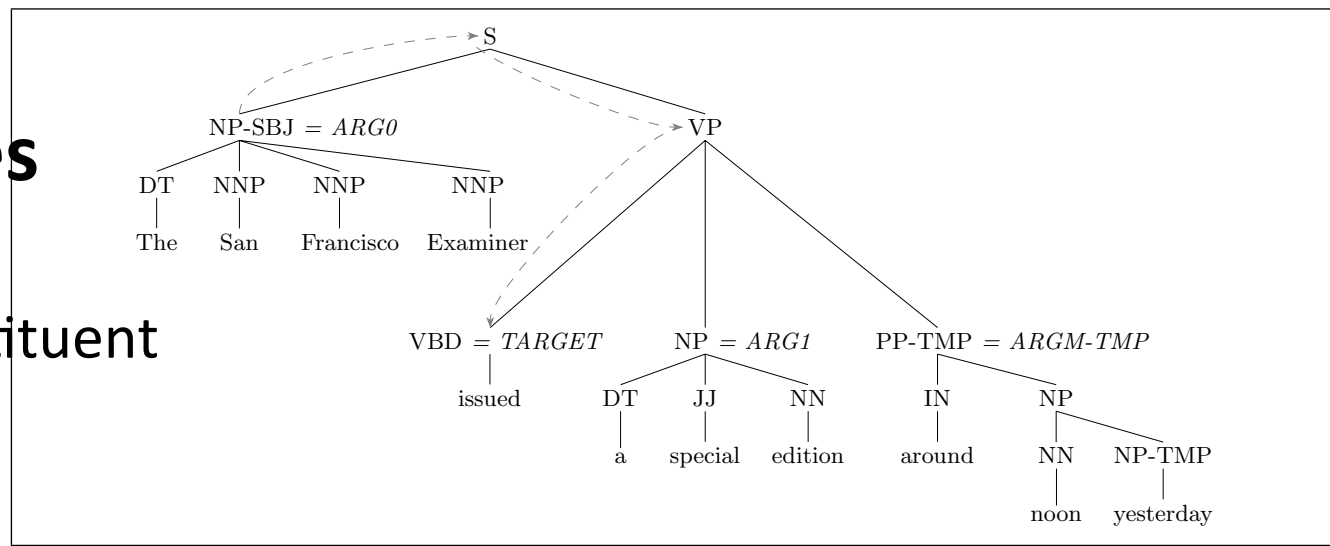
Headword of constituent

   Examiner

Headword POS

   NNP

Voice of the clause

   Active

Subcategorization of pred

   VP -> VBD NP PP

Named Entity type of constit
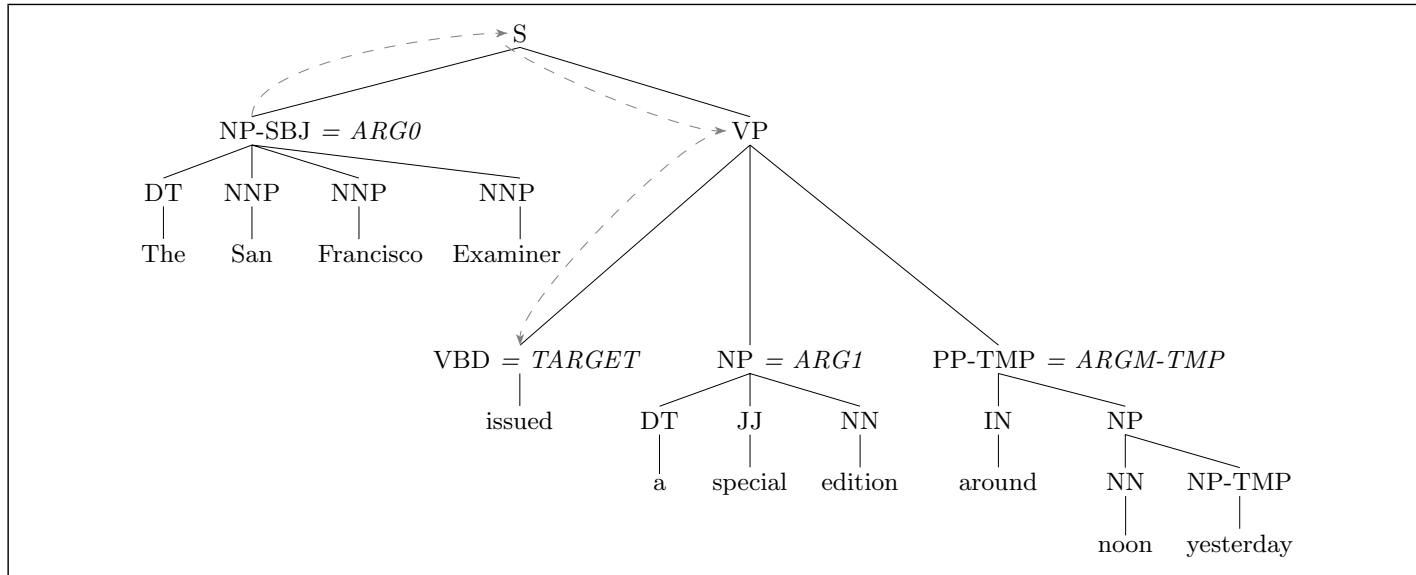
   ORGANIZATION

First and last words of constit

   The, Examiner

Linear position,clause re: predicate

   before

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Path Features

Path in the parse tree from the constituent to the predicate

$$NP{\uparrow}S{\downarrow}VP{\downarrow}VBD$$

Final feature vector

- For "The San Francisco Examiner",
- Arg0, [issued, NP, Examiner, NNP, active, before, VP→VBD NP PP, ORG, The, Examiner, NP↑S↓VP↓VBD]

- Other features could be used as well
  - sets of n-grams inside the constituent
  - other path features
    - the upward or downward halves
   - whether particular nodes occur in the path

3-step version of SRL algorithm

1. **Pruning**: use simple heuristics to prune unlikely constituents.
2. **Identification**: a binary classification of each node as an argument to be labeled or a NONE.
3. **Classification**: a 1-of-*N* classification of all the constituents that were labeled as arguments by the previous stage

Why add Pruning and Identification steps?

- Algorithm is looking at one predicate at a time

- Very few of the nodes in the tree could possibly be arguments of that one predicate

- Imbalance between
  - positive samples (constituents that are arguments of predicate)
  - negative samples (constituents that are not arguments of predicate)

- Imbalanced data can be hard for many classifiers

- So we prune the **very** unlikely constituents first, and then use a classifier to get rid of the rest.

Pruning heuristics – Xue and Palmer (2004)

- Add sisters of the predicate, then aunts, then great-aunts, etc
  - But ignoring anything in a coordination structure
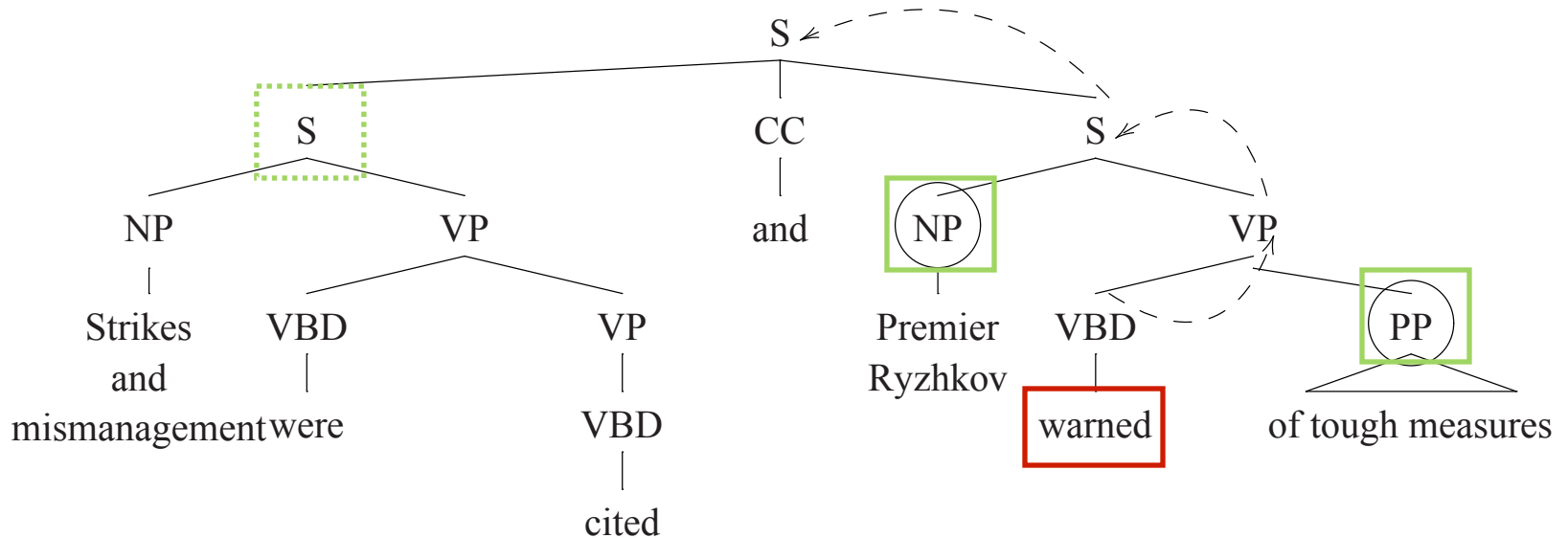
A common final stage: joint inference

- The algorithm so far classifies everything **locally –** each decision about a constituent is made independently of all others

- But this can't be right: Lots of **global** or **joint** interactions between arguments
  - Constituents in FrameNet and PropBank must be non-overlapping.
    - A local system may incorrectly label two overlapping constituents as arguments
    - PropBank does not allow multiple identical arguments
      - labeling one constituent ARG0
      - Thus should increase the probability of another being ARG1

How to do joint inference

- Reranking
  - The first stage SRL system produces multiple possible labels for each constituent
  - The second stage classifier the best **global** label for all constituents
  - Often a classifier that takes all the inputs along with other features (sequences of labels)

More complications: FrameNet

We need an extra step to find the frame

function SEMANTICROLELABEL(*words*) **returns** labeled tree

    parse ← PARSE(*words*)
    for each *predicate* **in** *parse* **do**
        Predicatevector ← ExtractFrameFeatures(predicate,parse)
        Frame ← ClassifyFrame(predicate,predicatevector)

        for each *node* **in** *parse* **do**
            featurevector ← EXTRACTFEATURES(*node*, *predicate*, *parse*)
            CLASSIFYNODE(*node*, *featurevector*, *parse* , Frame)

Features for Frame Identification

Das et al (2014)

the POS of the parent of the head word of t_i
the set of syntactic dependencies of the head word[21] of t_i
if the head word of t_i is a verb, then the set of dependency labels of its children
the dependency label on the edge connecting the head of t_i and its parent
the sequence of words in the prototype, w_ℓ
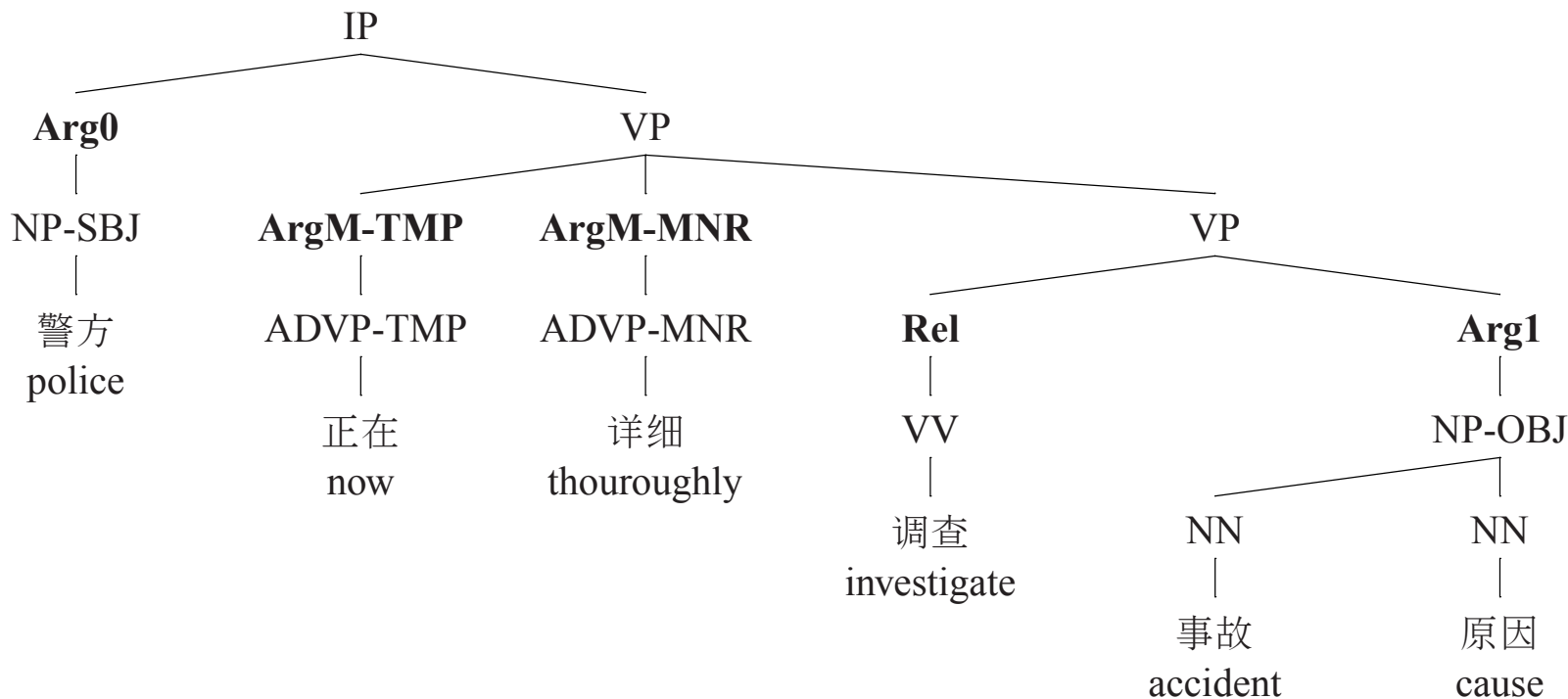the lemmatized sequence of words in the prototype
the lemmatized sequence of words in the prototype and their part-of-speech tags π_ℓ
WordNet relation[22] ρ holds between ℓ and t_i
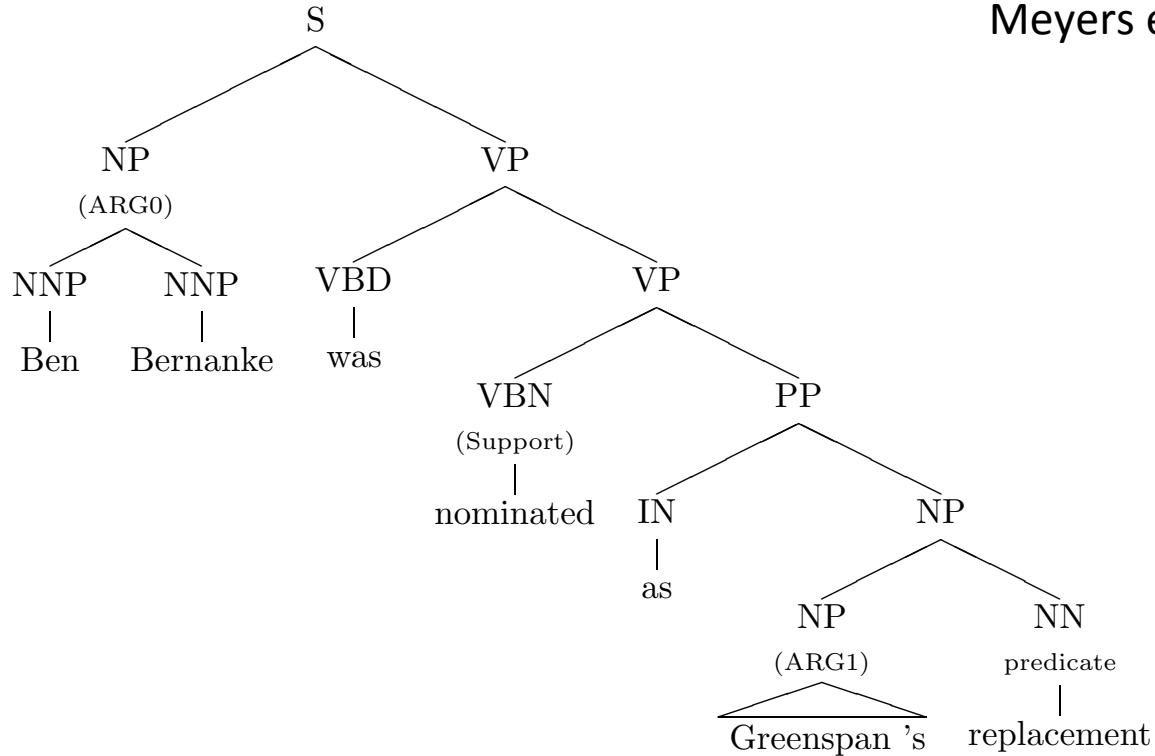WordNet relation[22] ρ holds between ℓ and t_i, and the prototype is ℓ
WordNet relation[22] ρ holds between ℓ and t_i, the POS tag sequence of ℓ is π_ℓ, and the POS tag sequence of t_i is π_t

Not just English

IP
Arg0 — NP-SBJ — 警方 / police
VP
ArgM-TMP — ADVP-TMP — 正在 / now
ArgM-MNR — ADVP-MNR — 详细 / thouroughly
VP
Rel — VV — 调查 / investigate
Arg1 — NP-OBJ
NN — 事故 / accident
NN — 原因 / cause

53 "The police are thoroughly investigating the cause of the accident."

Not just verbs: NomBank

Meyers et al. 2004

Figure from Jiang and Ng 2006

Additional Issues for nouns

- Features:
  - Nominalization lexicon (employment→ employ)
  - Morphological stem
    - Healthcare, Medicate → care
- Different positions
  - Most arguments of nominal predicates occur inside the NP
  - Others are introduced by support verbs
  - Especially light verbs "X made an argument", "Y took a nap"

Semantic Role Labeling

Conclusion

Semantic Role Labeling

- A level of shallow semantics for representing events and their participants
  - Intermediate between parses and full semantics
- Two common architectures, for various languages
  - FrameNet: frame-specific roles
  - PropBank: Proto-roles
- Current systems extract by
  - parsing sentence
  - Finding predicates in the sentence
    - For each one, classify each parse tree constituent