A Uniform Meaning Representation for NLP Systems:

Lecture 5: Knowledge Grounding and Logical Inference with UMR

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Joint work with Jens Van Gysel, Meagan Vigus, Jin Zhao, Nianwen Xue, Jayeol Chun, Kenneth Lai, Sara Moeller, Jiarui Yao, Tim O'Gorman, Andrew Cowell, William Croft, Chu-Ren Huang, Jan Hajič, James Martin, Stephan Oepen, Rosa Vallejos, Jingxuan Tu, Kyeongmin Rim, Bingyang Ye, Susan Brown

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Course Outline

- Monday: Formal Foundations of UMR and Extensions beyond AMR
- Tuesday: UMR Mechanisms for Quantification and Discourse Anaphora
- Wednesday: Annotation in UMR for Multiple Languages and Parsing UMRs
- Thursday: Extensions of UMR for Multimodal Communication and Situated Grounding
- Friday: UMR for Knowledge Grounding and Logical Inference

Mapping from VerbNet-GL to GLAMR

- VerbNet (VN) (Schuler, 2005; Brown et al., 2018,2022) as the primary lexical resource for identifying the canonical GL-event structure of each predicate

Subevent Structure in Generative Lexicon

Dynamic Event Structure

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- There may be many changes taking place within one atomic event, when viewed at the subatomic level.

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     $[\alpha]\phi$ (after every execution of α, ϕ is true);
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     $\langle\alpha\rangle\phi$ (there is an execution of α, such that ϕ is true);
  5. Formulas can become programs, $\phi?$ (test to see if ϕ is true, and proceed if so).

Simple First-order Transition

$x := y$ (ν-transition)
"x assumes the value given to y in the next state."
$\langle \mathcal{M}, (i, i+1), (u, u[x/u(y)]) \rangle \models x := y$
iff $\langle \mathcal{M}, i, u \rangle \models s_1 \wedge \langle \mathcal{M}, i+1, u[x/u(y)] \rangle \models x = y$

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$$\begin{tikzcd}
 & e^{[i,i+1]} \arrow[dl, dash] \arrow[dr, dash] & \\
e_1^{i} \arrow[rr, "x := y"] \arrow[d, dash] & & e_2^{i+1} \arrow[d, dash] \\
\mathcal{A}(z) = x & & \mathcal{A}(z) = y
\end{tikzcd}$$

Processes

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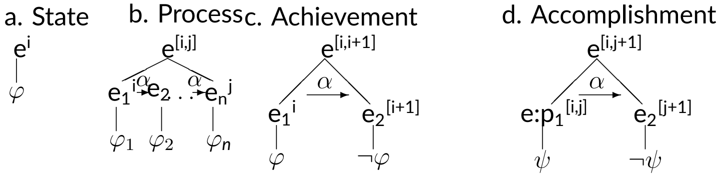
$$e$$

$$e_1 \xrightarrow{\nu} e_2 \ \ldots \xrightarrow{\nu} \ e_n$$

Event Structure with a dimension of scalar change

- Dynamic Event Structure (DES): ES enriched to track dynamically object attributes modified in the course of the event (Pustejovsky and Moszkowicz 2011).
- All the events are represented as a sequence of states related by functions (programs) which go from state to state.



Mapping from VerbNet-GL to GLAMR

- Each VN class is associated with multiple frames on the possible compositions of the verb sense (left)
- Each Frame shows its syntax and GL-event structure (right)

NP V NP.patient
NP V NP PP.instrument
NP.patient V
NP V ADV-Middle
NP.instrument V NP
NP V NP PP.result
NP V NP PP.result PP.instrument
NP V PP.result
NP V PP.result PP.instrument

EXAMPLE:

Jennifer baked the potatoes in the oven.

SHOW DEPENDENCY PARSE TREE

SYNTAX:

Agent VERB Patient { in on with } Instrument

SEMANTICS:

¬ COOKED(e1 , Patient , V_Final_State)
DO(e2 , Agent)
UTILIZE(e2 , Agent , Instrument)
APPLY_HEAT(ë3 , Instrument , Patient)
CAUSE(ë3 , e4)
COOKED(e4 , Patient , V_Final_State)

FORCE DYNAMICS:

None

Mapping from VerbNet-GL to GLAMR

- Each VN class is also associated with a group of lemmas

Member Verb Lemmas:

BAKE	BARBECUE	BARBEQUE	BLANCH	BOIL	BRAISE	BROIL	BROWN
CARAMELIZE	CHAR	CHARBROIL	CHARCOAL-BROIL	CODDLE	COOK	CRISP	
DEEP-FRY	FRENCH-FRY	FRY	GRILL	HARDBOIL	HEAT	MICROWAVE	
OVEN-FRY	OVEN-POACH	OVERBAKE	OVERCOOK	OVERHEAT	PAN-BROIL		
PAN-FRY	PARBOIL	PARCH	PERCOLATE	PERK	PICKLE	PLANK	POACH
POT-ROAST	REHEAT	RISSOLE	ROAST	SAUTE	SCALD	SCALLOP	SEAR
SHIRR	SIMMER	SOFTBOIL	STEAM	STEAM-BAKE	STEEP	STEW	
STIR-FRY	TOAST	WARM_UP					

Mapping from VerbNet-GL to GLAMR

- Given the GL-event structure from VN, for the predicate node `pred-01`, and the subevent `se(E1, ROLE1, ROLE2)`, we propose the general form for the GLAMR:
- ```
  (p / pred-01
       :event-structure (se / subevents
            :E1 (sub1 / subevent
                 :ROLE1 [value1]
                 :ROLE2 [value2]))
  ```
    - subevent index: `:Ex` (E1, E2, ...)
    - subevent names: `subevent`
    - subevent roles: `ROLE1`, `ROLE2`
  ```

Subevent Sequence in GLAMR

- GL-event structure of a predicate contains multiple subevent
- GLAMR graph only includes subevents that contain as least one `Patient` or `Theme` role (for tracking the change of the object)

    Example: Pour them into the bowl.

```
HAS_LOCATION(e1, Theme, Initial_Loc.)
HAS_LOCATION(e4, Theme, Destination)

(p / pour-01
  :ARG0 (y / you)
  :ARG1 (t / them)
  :ARG3 (b / bowl)
  :event-structure (se / subevents
      :E1 (se1 / has_location
        :THEME t
        :INITIAL_LOC N/A)
      :E4 (se4 / has_location
        :THEME t
        :DESTINATION b)
  :mode imperative)
```

Action Subevent in GLAMR

- Given the nature of the procedural texts in the data, GLAMR incorporates the `:ACTION` subevent into the predicate
- The subevent represents the action that has been performed on the objects during the event time

Example: Wash the cranberries.

```
(w / wash-01
  :ARG0 (y / you)
  :ARG1 (c / cranberries)
  :event-structure (se / subevents
      :E0 (se0 / do
        :ACTION (w1 / wash))
      [... ...]
  :mode imperative)
```

Negation in GLAMR

- GL-event structure use logical connective "¬" to represent the negation of the subevent state (`¬COOK` == "uncooked" or "not cooked")
- GLAMR uses the attribute `:polarity` to represent the negation

  Example: Wash the cranberries.

```
¬HAS_STATE(e1, Patient, V_Final_State)
HAS_STATE(e3, Patient, V_Final_State)

(w / wash-01
  :ARG0 (y / you)
  :ARG1 (c / cranberries)
  :event-structure (se / subevents
      :E1 (se1 / has_state
        :polarity -
        :PATIENT c
        :V_FINAL_STATE (w1 / washed))
      :E3 (se3 / has_state
        :PATIENT s4c
        :V_FINAL_STATE w1)
      [... ...]
  :mode imperative)
```

Simultaneous Subevents in GLAMR

- GL-event structure also contains subevents that happen simultaneously denoted by the same subevent index (e.g., two `E0`).
- Subevents with the same index in GLAMR are stacked with the `:op` roles

  Example: Roll the cranberries in the sugar.

```
MOTION(e2 ,Theme ,Trajectory)
¬HAS_LOCATION(e2 ,Theme ,Initial_Loc.)
HAS_LOCATION(e3, Theme, Destination)

(r / roll-01
  :ARG0 (y / you)
  :ARG1 (c / cranberries)
  :ARG2 (s / sugar)
  :event-structure (se / subevents
      :E2 (se2 / and
        :op1 (se21 / motion
          :THEME c
          :TRAJECTORY N/A)
        :op2 (se22 / has_location
          :polarity -
          :THEME c
          :INITIAL_LOC N/A))
      [... ...]
  :mode imperative)
```

Data Preparation

- Randomly sampled 15 recipes from the R2VQ corpus (Tu et al., 2022a).
- Use AMR parser to parse each recipe sentence into a PENMAN graph, which is then dually annotated and validated.
- Disagreements between annotators are adjudicated, and a finalized gold standard AMR annotation is created.

# of	**Count**
Documents	15
Sentences / PENMAN Graphs	137
Predicates	197

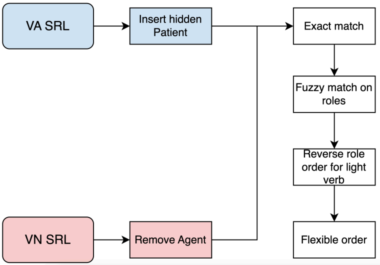
Table: Count of PENMAN graphs and predicates in the 15 recipes from our data.

Sense and Role Mapping

- The VerbAtlas verb sense (Di Fabio et al., 2019) from the SRL annotation is mapped to the PropBank (PB) sense using provided mapping files.
- Use mapping files in Semlink (Stowe et al., 2021) to connect PB verb senses to corresponding VerbNet classes (VN) and their subevent structures.
- VerbNet-GL (Brown et al., 2018, 2022) is used as the resource for the subevent structure in GLAMR.

Subevent Structure Identification

- Each VerbNet class can have multiple different frames.
- Leverage the SRLs in both VerbNet and R2VQ corpus to extract the correct VerbNet frame and its unique subevent structure.
- Built a pipeline with heuristics since the SRLs are not always perfect match.

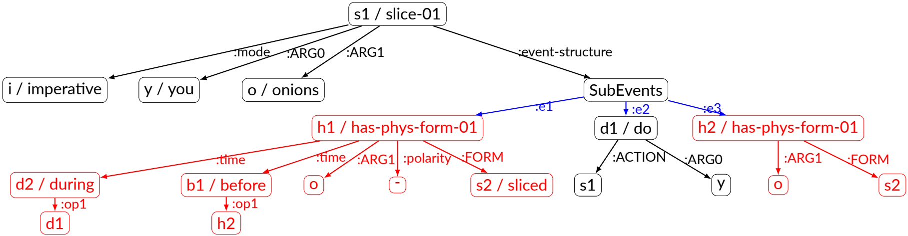


GLAMR Generation

- Generate final GLAMR graphs by integrating the fulfilled predicate subevent structure into the gold-standard AMR graphs using token alignment information.
- Subevent names often involve changes of locations and event states, and the most frequent subevent roles involve objects undergoing changes, locations, and tools used.
- GL-event structure is effective for enriching AMR with fine-grained subevent information in the cooking domain.

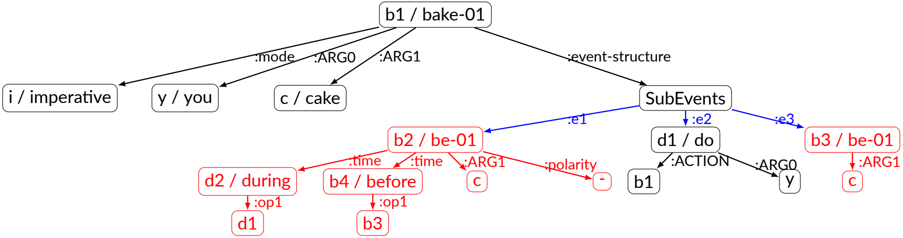
Subevent Names	**Count**	**Subevent Roles**	**Count**
has_location	102	Patient	262
motion	49	Theme	223
¬has_location	49	Initial_Loc.	94
cooked	30	V_Final_State	74
¬cooked	30	Trajectory	50
apply_heat	30	Destination	50
together	20	Instrument	36
has_state	19	V_State	30

GLAMR - Transformation



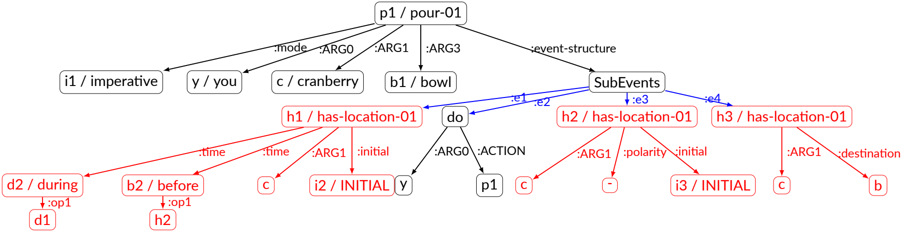
Slice the onions.

GLAMR - Creation



Bake the cake.

GLAMR - Change of Location

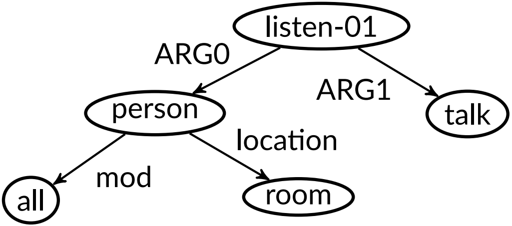


Pour the cranberries into a large bowl.

A Continuation Semantics for AMR

- AMR comes with a “logical form”

Everyone in the room listened to a talk.




```
(l / listen-01
      :ARG0 (p / person
              :mod (a / all)
              :location (r / room))
      :ARG1 (t / talk))
```

instance(l, listen-01)$\wedge$instance(p, person)$\wedge$instance(a, all)$\wedge$instance(r, room)$\wedge$ instance(t, talk) $\wedge$ ARG0(l, p) $\wedge$ mod(p, a) $\wedge$ location(p, r) $\wedge$ ARG1(l, t)

A Continuation Semantics for AMR

- However, this logical form cannot be used to draw inferences
    - Quantifiers and negation treated as ordinary modifiers
        - Infer “a dog barked” from “a dog didn’t bark”
    - No representation of quantifier scope

A Continuation Semantics for AMR

- Idea: use continuations to translate AMR to first-order logic
- The continuation hypothesis: meanings of expressions are functions of their contexts (Barker, 2002; Barker and Shan, 2014)
    - Continuations: set of contexts that, when combined with an expression, result in a true sentence

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(b / bark-01
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  - We know it's the `ARG0` of something, so let's say $\lambda n.\mathrm{ARG0}(m, n)$
- What about the continuation of `(b / bark-01)`?
  - Two parts: the dog $[\![$`(d / dog)`$]\!](\lambda n.\mathrm{ARG0}(m, n))$, and ϕ, the rest of the sentence (if any)

Continuations

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(b / bark-01
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```
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$$\lambda\phi.[\![\texttt{(b / bark-01)}]\!](\lambda m.[\![\texttt{(d / dog)}]\!](\lambda n.\mathrm{ARG0}(m,n)) \wedge \phi(m))$$

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- In AMR, all variables are assumed to be existentially quantified
  - $[\![\texttt{(b / bark-01)}]\!] = \lambda\psi.\exists b.\mathrm{bark\text{-}01}(b) \wedge \psi(b)$ ("a bark")
  - $[\![\texttt{(d / dog)}]\!] = \lambda\chi.\exists d.\mathrm{dog}(d) \wedge \chi(d)$ ("a dog")

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$\exists b.\mathrm{bark\text{-}01}(b) \wedge \exists d.\mathrm{dog}(d) \wedge \mathrm{ARG0}(b,d)$

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$\rightsquigarrow \exists d.\mathrm{dog}(d) \wedge \exists b.\mathrm{bark\text{-}01}(b) \wedge \mathrm{ARG0}(b,d)$

- Methods of marking scope:
  - "\" for projection/wide scope (Bos, 2016)
  - Scope node (Pustejovsky et al., 2019)
  - ...

Detailed Derivation

$$[\![c]\!] = \lambda\phi.\phi(c)$$
$$[\![x]\!] = \lambda\phi.\phi(x)$$
$$[\![(x|P :R_1(y\backslash Q\ldots) :R_iA_i)]\!] = \lambda\phi.[\![(y\backslash Q\ldots)]\!](\lambda n.[\![(x|P :R_iA_i)]\!](\lambda m.R_1(m,n)\wedge\phi(m)))$$
$$[\![(x|P :R_1A_1 :R_iA_i)]\!] = \lambda\phi.[\![(x|P :R_iA_i)]\!](\lambda m.[\![A_1]\!](\lambda n.R_1(m,n))\wedge\phi(m))$$
$$[\![(x|P)]\!] = \lambda\phi.\exists x.P(x)\wedge\phi(x)$$

$$\begin{aligned}
&[\![\text{a dog scratched itself}]\!]\\
&= \lambda\phi.[\![\text{a dog}]\!](\lambda n.[\![\text{scratched itself}]\!](\lambda m.\text{ARG0}(m,n)\wedge\phi(m)))\\
&= \lambda\phi.[\![\text{a dog}]\!](\lambda n.(\lambda\psi.\exists s.\text{scratch-01}(s)\wedge\text{ARG1}(s,d)\wedge\psi(s))(\lambda m.\text{ARG0}(m,n)\wedge\phi(m)))\\
&= \lambda\phi.[\![\text{a dog}]\!](\lambda n.\exists s.\text{scratch-01}(s)\wedge\text{ARG1}(s,d)\wedge(\lambda m.\text{ARG0}(m,n)\wedge\phi(m))(s))\\
&= \lambda\phi.[\![\text{a dog}]\!](\lambda n.\exists s.\text{scratch-01}(s)\wedge\text{ARG1}(s,d)\wedge\text{ARG0}(s,n)\wedge\phi(s))\\
&= \lambda\phi.(\lambda\psi.\exists d.\text{dog}(d)\wedge\psi(d))(\lambda n.\exists s.\text{scratch-01}(s)\wedge\text{ARG1}(s,d)\wedge\text{ARG0}(s,n)\wedge\phi(s))\\
&= \lambda\phi.\exists d.\text{dog}(d)\wedge(\lambda n.\exists s.\text{scratch-01}(s)\wedge\text{ARG1}(s,d)\wedge\text{ARG0}(s,n)\wedge\phi(s))(d)\\
&= \lambda\phi.\exists d.\text{dog}(d)\wedge\exists s.\text{scratch-01}(s)\wedge\text{ARG1}(s,d)\wedge\text{ARG0}(s,d)\wedge\phi(s)\\
&\rightsquigarrow \exists d.\text{dog}(d)\wedge\exists s.\text{scratch-01}(s)\wedge\text{ARG1}(s,d)\wedge\text{ARG0}(s,d)
\end{aligned}$$

Universal Quantification

- In AMR, all variables are assumed to be existentially quantified
    - $[\![\texttt{(d / dog)}]\!] = \lambda\phi.\exists d.\mathrm{dog}(d) \wedge \phi(d)$

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See paper for more details!

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  - Narrow-scope (attaches to predicate)
    - $\forall d.\neg\text{dog}(d) \rightarrow \exists m.\text{meow-01}(m) \wedge \text{ARG0}(m, d)$
      "Every non-dog meowed."

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    - Arguments of an event should be projective in general
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Future Work

- Extending the translation to other semantic phenomena (e.g., Uniform Meaning Representation)
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- Dynamic semantics
  - "Discourse moves as continuations"

UMR summary

- UMR is a rooted directed node-labeled and edge-labeled document-level graph.
- UMR is a document-level meaning representation that builds on sentence-level meaning representations
- UMR aims to achieve semantic stability across syntactic variations and support logical inference
- UMR is a cross-lingual meaning representation that separates language-general aspects of meaning from those that are language-specific
- We are testing UMR English, Chinese, Arabic, Arapaho, Kukama, Sanapana, Navajo

References

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