# A Uniform Meaning Representation for NLP Systems:

## Lecture 1: Formal Foundations of UMR; Extensions beyond AMR

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# Course Outline

- Monday: Lexical semantic representations: PropBank AMR and motivation for Uniform Meaning Representations
- Tuesday: UMR Mechanisms for Quantification and Discourse Anaphora
- Wednesday: Annotation in UMR for Multiple Languages
- Thursday: Extensions of AMR/UMR for Multimodal Communication and Situated Grounding
- Friday: AMR/UMR for Knowledge Grounding and Logical Inference

# Do we need a new meaning representation?

- Existing meaning representations vary a great deal in their focus and perspective
  - Formal semantic representations for *logical inference* (e.g. MRS, DRT) focus on the proper representation of:
    - quantification
    - negation
    - tense
    - modality
  - Lexical semantic representations (e.g. TR, AMR) focus on the proper representation of:
    - core predicate-argument structures
    - word senses
    - named entities
    - co-reference

# Do we need a new meaning representation?

- Existing meaning representations vary a great deal in the "semantic vocabulary" they use:
  - One extreme: no classification of named entities at all (MRS)
  - Other extreme: over 100 types of named entities (AMR)
- Existing meaning representations are often developed based on English / high-resource languages
  - Their structures and workflows therefore pose challenges for the annotation of typologically different languages

# The MATTER Cycle

Pustejovsky and Stubbs (2012)

(1) a. **Model**: Structural descriptions provide theoretically-informed attributes derived from empirical observations over the data;
b. **Annotate**: Annotation scheme assumes a feature set that encodes specific structural descriptions and properties of the input data;
c. **Train**: Algorithm is trained over a corpus annotated with the target feature set;
d. **Test**: Algorithm is tested against held-out data;
e. **Evaluate**: Standardized evaluation of results;
f. **Revise**: Revisit the model, annotation specification, or algorithm, in order to make the annotation more robust and reliable.

# MATTER and MAMA

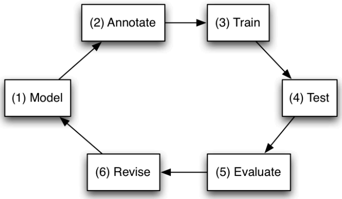



Figure: The MATTER Methodology

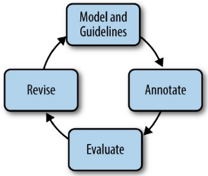



Figure: The MAMA Sub-cycle

# Annotating Semantic Relations in Text

- PropBank/VerbNet
- FrameNet
- Minimal Recursion Semantics (MRS)
- Abstract Meaning Representation (AMR)

# Minimal Recursion Semantics (MRS)

Copestake et al (2006)

- Expressive Adequacy. The framework must allow linguistic meanings to be expressed correctly.
- Grammatical Compatibility. Semantic representations must be linked cleanly to other kinds of grammatical information (most notably syntax).
- Computational Tractability. It must be possible to process meanings and to check semantic equivalence efficiently and to express relationships between semantic representations straightforwardly.
- Underspecifiability. Semantic representations should allow underspecification (leaving semantic distinctions unresolved), in such a way as to allow flexible, monotonic resolution of such partial semantic representations.

# Sample MRS Representation

Every dog chases some white cat.

(2) a. Existential quantifier has wider scope:
b. some(y, white(y) $\wedge$ cat(y), every(x, dog(x), chase(x, y)))
c. h1: every(x, h3, h4), h3: dog(x), h7: white(y), h7: cat(y), h5: some(y, h7, h1), h4: chase(x, y)

(3) a. Universal quantifer has wider scope:
b. every(x, dog(x),some(y, white(y) $\wedge$ cat(y), chase(x, y)))
c. h1: every(x, h3, h5), h3: dog(x), h7: white(y), h7: cat(y), h5: some(y, h7, h4), h4: chase(x, y)

(4) a. Underspecified representation:
b. h1: every(x, h3, h8), h3: dog(x), h7: white(y), h7: cat(y), h5: some(y, h7, h9), h4: chase(x, y)

# Representing MRS Graphically

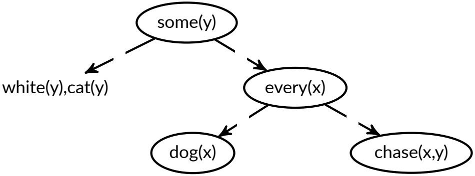



Figure: wide scope for existential quantifier

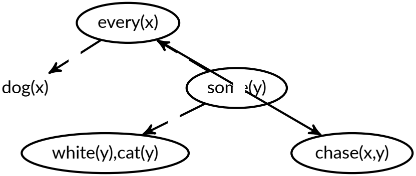



Figure: wide scope for universal quantifier

# What MRS in practice does not Represent

- The predicate-structure aspect of the sentence semantics is often underdeveloped and never highlighted.
- No lexico-semantic support for how the arguments are labeled and what senses the predicates take.
- Quantifier scope is underspecified even when it can be disambiguated in context (DeepBank implementation).

# Negatives for MRS as an Annotation Language

- Flat representation reveals no semantic core to annotate.
- While expressive, human annotation is cumbersome.
- Resulting annotation is difficult to interpret and inspect.

# Abstract Meaning Representations (AMR)

- A rooted, acyclic, directed graph used to represent the meaning of English sentences.
- It builds on work annotating the argument structure of verbal and nominal predicates, using Propbank valency lexicon, where senses and their semantic roles are specified.
- Syntactically it uses the Penman notation and the semantic structure of each sentence closely resembles that of a dependency tree ...
- except when there is re-entrancy, where the same concept is an argument for multiple predicates.
- Since each argument of a predicate is labeled with a semantic role, interpretation does not depend on order in which it appears in the sentence, and abstracts away from its morpho-syntactic variations.

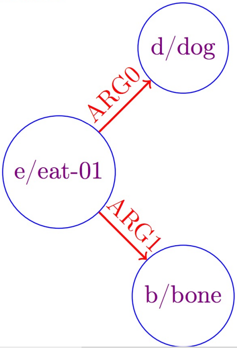
# Abstract Meaning Representations (AMR)

NAACL-HLT Tutorial 2015
Nathan Schneider, Jeffrey Flanigan, and Tim O'Gorman

- The edges (ARG0 and ARG1) are **relations**
- Each node in the graph has a **variable**
- They are labeled with **concepts**
- **d** / **dog** means "**d** is an instance of **dog**"

*"The dog is eating a bone"*

(**e** / **eat-01**
    :**ARG0** (**d** / **dog**)
    :**ARG1** (**b** / **bone**))



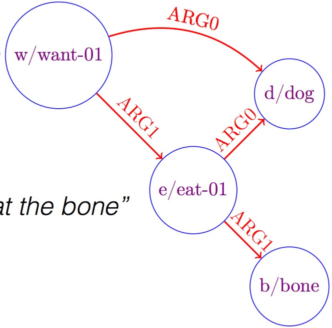
# Abstract Meaning Representations (AMR)

NAACL-HLT Tutorial 2015
Nathan Schneider, Jeffrey Flanigan, and Tim O'Gorman

- What if something is referenced multiple times?
- Notice how **dog** has two incoming roles now.
- To do this in PENMAN format, repeat the variable. We call this a **reentrancy**.

*"The dog **wants to** eat the bone"*

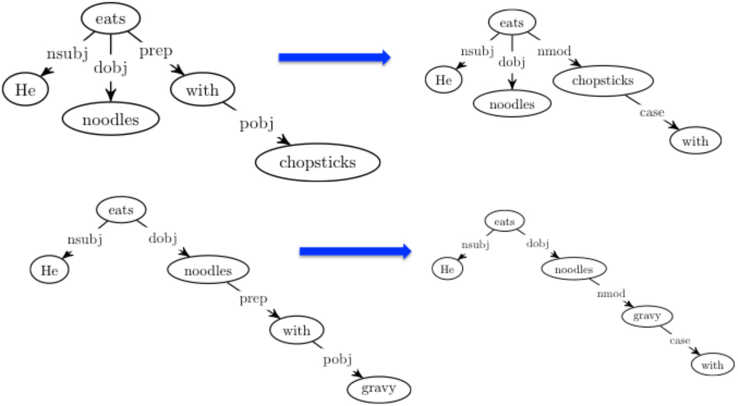
```
(want-01
    :ARG0 (d / dog)
    :ARG1 (e / eat-01
        :ARG0 d
        :ARG1 (b / bone)))
```



# Universal Dependencies

- The primacy of content words: Dependency relations hold primarily between content words, rather than being indirect relations mediated by function words.
- Function words normally do not have dependents of their own. Multiple function words related to the same content words are typically siblings
- The dependency relations are described by a mixture of functional and structural notions: advmod vs nmod
- There is some machinery to account for word order variations: nsbj vs nsbjpass
- In coordination structures, the first conjunct is the head, and all other conjuncts depend on it. So are the coordinating conjunctions.

# Primacy of Content Words



# Comparison between UD, SDP and AMR

| Attributes | SRL | UD | SDP | AMR |
|---|---|---|---|---|
| Normalizes syntactic variations | yes | no | yes | yes |
| Predicate sense | yes | no | no | yes |
| Primacy of content words | n/a | yes | yes | yes |
| Leaves function words unattached | no | no | yes | yes |
| A complete and connected structure for a sentence | no | yes | yes | yes |
| Allows re-entrancy (graph) | n/a | no | yes | yes |
| Named entities | no | no | no | yes |
| Relations between named entities | no | no | no | yes |
| Polarity and modality | no | no | no | yes |

# Why is abstraction good?

- "Normalizes" different realizations of the same meaning, supports similarity based inference that helps applications such as text comprehension.

Text: … Katie also has a dog, but he does not like Bows.
… His name is Sammy. …

Question: What is the name of Sammy's dog? Answer: Sammy.

Hypothesis: Sammy is the name of Katie's dog

From *(Sachan and Xing 2016)*

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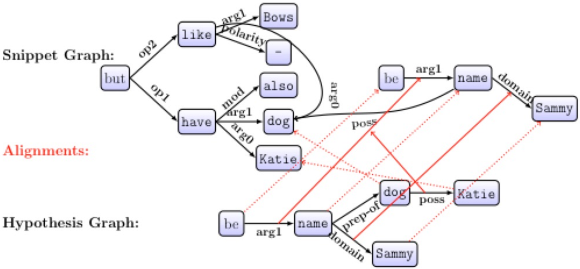
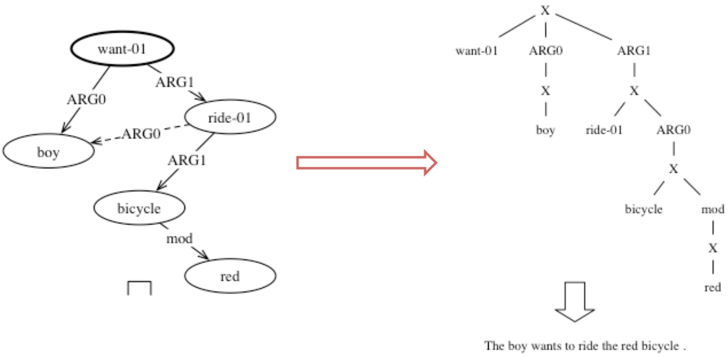



Hypothesis: Sammy is the name of Katie's dog.
Question: What is the name of Katie's dog. Answer: Sammy

From *(Sachan and Xing 2016)*

# Why is abstraction good?

- Supports natural language generation

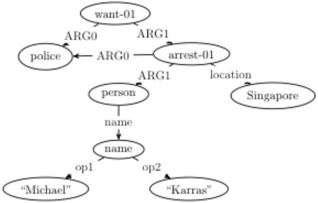


# AMR parsing approaches

- Approaches that focus on addressing the "abstract" nature of AMR
  - Dependency Tree to AMR graph transduction (Wang et al 2015a, Wang et al 2015b, Wang et al 2016)
  - String to tree translation (Pust et al 2015)
- Approaches that focus on the "graph" aspect of the AMR
  - AMR parsing based on Synchronous Hyper-edge Replacement Grammar (SHRG) (Peng et al 2015)
  - MSCG: Maximum Spanning Connected Graph (Flanigan et al 2014)

# Tree-to-AMR graph transduction


(a) Dependency tree

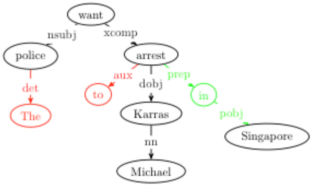



(b) AMR graph

*The police wants to arrest Micheal Karras in Singapore.*

Linguistically, there are many similarities between an AMR and the dependency structure of a sentence.

# Tree-to-AMR graph transduction




(a) Dependency tree


(b) AMR graph

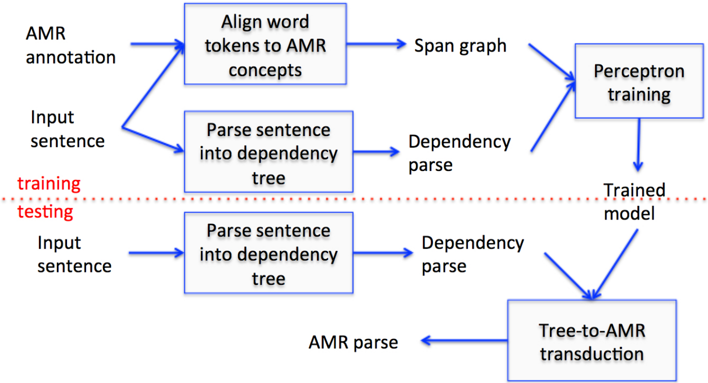
*The police wants to arrest Micheal Karras in Singapore.*

Wang et al, 2015a, 2015b

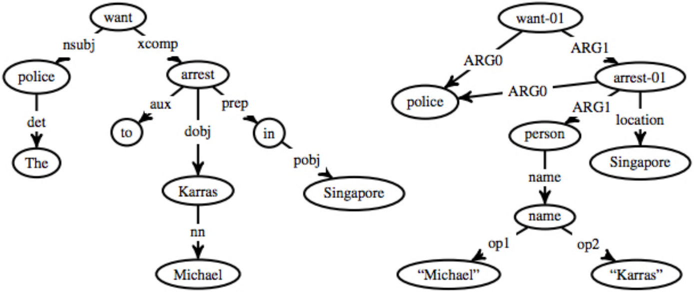
# Why start with Dependency Structures?

- Significant similarity between a dependency structure and AMR in terms of the bare-bone structure
- Large amount of dependency data (converted from phrase structure trees in the case of English) already exists. State-of-the-art dependency parsers are already very accurate
- In contrast, the AMR Annotation Bank is relatively small.

# Transition-based AMR parsing



# Dependency Tree to AMR Graph Transduction




(a) Dependency tree (b) AMR graph

Figure 1: Dependency tree and AMR graph for the sentence, "The police want to arrest Micheal Karras in Singapore."

# Token-level AMR to sentence alignment

- Unlike dependency parses, there is no inherent alignment between concepts in an AMR graph and word tokens in a sentence
- AMR annotation (currently) has no explicit alignment to sentence
- Training data has whole sentence-AMR pairs
- So the first step is automatic alignment
- Rule-based and EM-based alignment

# What AMR fails to Represent properly

AMR does not provide good support for logical inference because it does not yet properly handle scoping and other phenomena.

- quantifiers
- negation
- modality
- Aktionsarten and aspectual classes

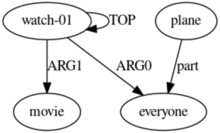
# Advantages of AMR-style Annotation

- Focuses on the intuitive *predicative core* of the sentence.
- Lower cognitive load for annotation by non-experts.
- Semantic relations are transparent in the graphical representation.

# Quantifier Scope in AMR

(5) a. Everyone in the room was listening to a talk.
$\exists y[talk(y) \wedge \forall x[person(x) \wedge inRoom(x) \rightarrow listen(x, y)]]$

b. Everyone on the plane was watching a movie.
$\forall x[[person(x) \wedge onPlane(x)] \rightarrow \exists y[movie(y) \wedge watch(x, y)]]$

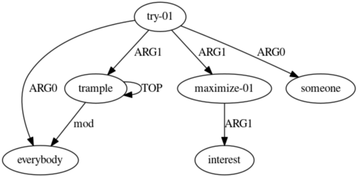


# Quantifier Scope in AMR

(6) Everyone drank a coffee at break.
b. $\forall x[person(x) \rightarrow \exists y[coffee(y) \wedge drink(x, y)]]$

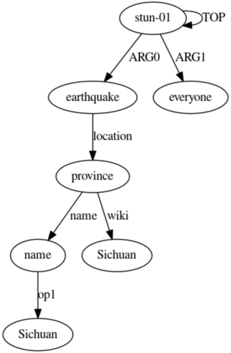
# No Account for Quantifier Scope

(7) Everybody tramples over someone trying to maximize their own interests.



# No Account for Quantifier Scope

(8) An earthquake in Sichuan stunned everyone.




(9) a. Everyone here has had a COVID vaccine shot.
b. Everyone here has had the Moderna vaccine.

# Towards a Uniform Meaning Representation (UMR)

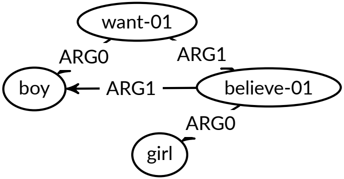
- A representation based primarily on AMR, but adds facility to properly represent scope so that it can support logical inference.
- We believe both lexical and logical inference are needed to support natural language applications, especially those that require deep natural language understanding.
- UMR is also intended to be cross-linguistically valid, meaning the concepts and relations posited for AMR will need to be validated based on principles in linguistic typology.
- New concepts and relations may need to be added and some concepts and relations may need to be revised against cross-linguistic evidence.

# The UMR Project

- UMR (Uniform Meaning Representation) is an NSF-funded collaborative project between Brandeis University, University of Colorado, and University of New Mexico
- Our starting point is AMR, which has a number of attractive properties:
  - Easy to read
  - Scalable (does not rely on syntactic structures)
  - Information that is important to downstream applications (e.g., semantic roles, named entities and coreference)
  - Well-defined mathematical structure (single-rooted, directed, acylical graph)
- UMR augments AMR with meaning components that are missing and adapts it to cross-lingual settings

# Transitioning from AMR

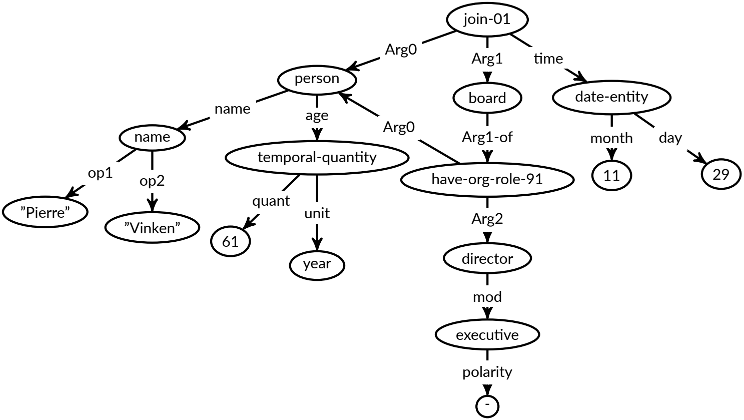
- Single-rooted, directed, acylic graph
- Nodes are concepts (sense-disambiguated predicates, named entity types, plain lemmas)
- Edges are relations (participant roles, other semantic relations)




```
(w / want-01
:ARG0 (b / boy)
:ARG1 (b2 / believe-01
            :ARG0 (g / girl)
            :ARG1 b))
```

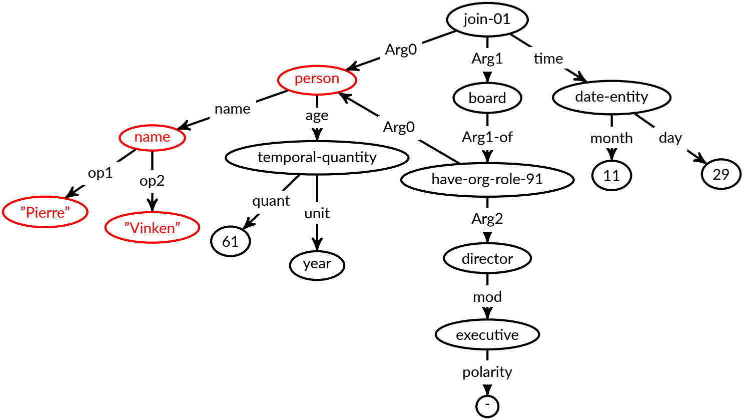
"The boy wants the girl to believe him."
Banarescu et al. (2013)

# Transitioning from AMR



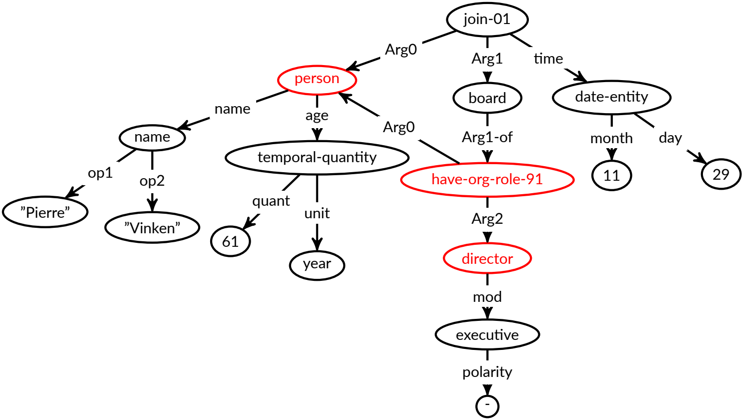

"Pierre Vinken , 61 years old , will join the board as a nonexecutive director Nov. 29 ."

# AMR: Named Entities




“Pierre Vinken , 61 years old , will join the board as a nonexecutive director Nov. 29 .”

# AMR: Relations

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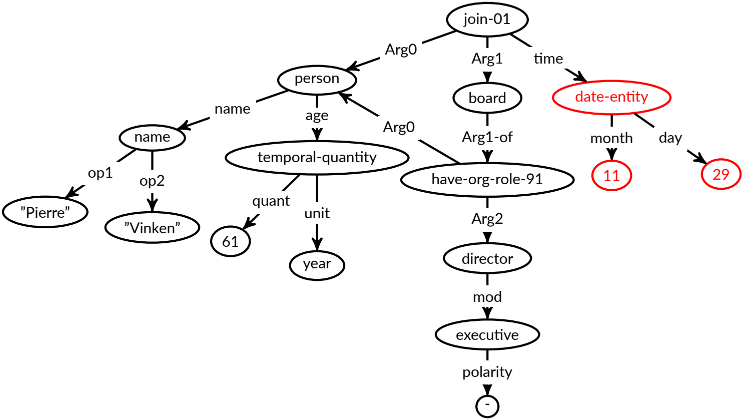
# AMR: Date entities

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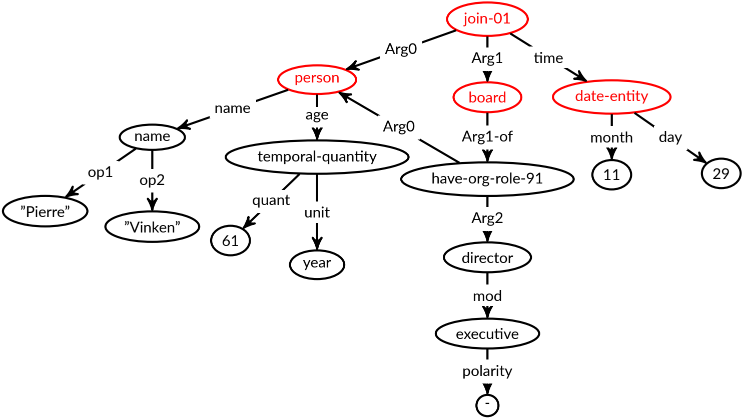
# AMR: Word sense and semantic roles




"Pierre Vinken , 61 years old , will join the board as a nonexecutive director Nov. 29 ."

# Defining UMR

(Van Gysel et al., 2021)

- To make UMR cross-linguistically applicable, it:
    - defines a set of language-independent abstract concepts and participant roles,
    - uses lattices to accommodate linguistic variability,
    - provides meaning-based guidelines for the identification of events,
    - designs specifications for complicated mappings between words and UMR concepts,
    - is organized as a road map so that languages at different stages of documentation and description can use UMR at an appropriate level of detail.

# Defining UMR

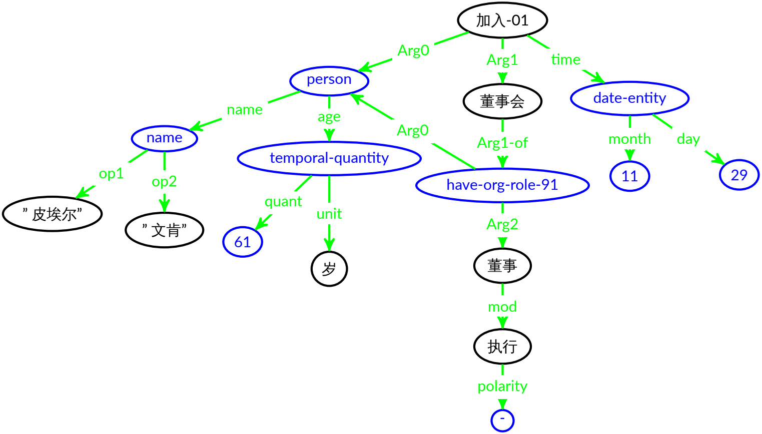
(Van Gysel et al., 2021)

- At the sentence level, UMR adds:
    - An *Aspect* attribute to eventive concepts
    - *Person* and *Number* attributes for pronouns and other nominal expressions
    - A principled set of discourse relations
    - Quantification scope between quantified expressions
- At the document level UMR adds:
    - Temporal dependencies in lieu of tense
    - Modal dependencies in lieu of modality
    - Coreference relations beyond sentence boundaries

# UMR is a cross-lingual meaning representation

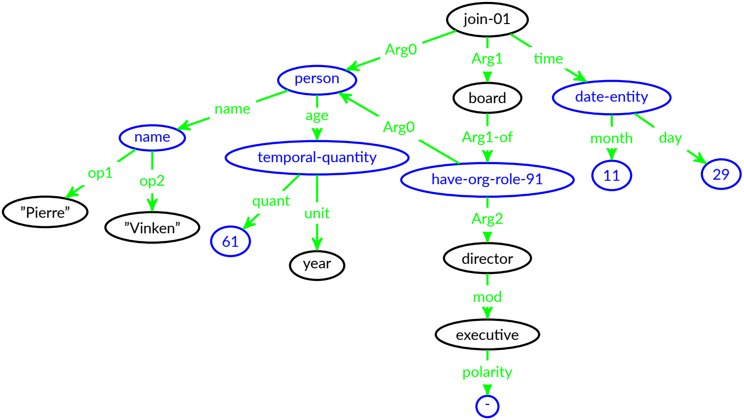
- Abstract concepts (e.g., *person*, *thing*, *have-org-role-91*) are uniform across languages
    - Concepts that do not always have explicit lexical support but can be inferred from context
- UMR defines a set of general participant roles (e.g., *agent*, *theme*, *causer*) and non-participant relations that are uniform across languages
- But UMR is still not an Interlingua:
    - Lexical concepts include sense-disambiguated lemmas or simple lemmas and are language-specific (e.g., Mandarin 加入*.01* vs. English *join-01* vs. Sanapaná *empahlkay'a*)
    - Languages can define their own lexicalized participant roles (e.g., *:ARG0* of 加入.01)
- In general, grammatical meaning is language-independent while lexical meaning is language-specific

# Language-independent vs language-specific aspects




“61 岁的 Pierre Vinken 将于 11 月 29 日加入董事会，担任非执行董事。”

# Language-independent vs language-specific aspects

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# Abstract concepts in UMR

- Abstract concepts inherited from AMR:
  - Standardization of quantities, dates etc.: *have-name-91*, *have-frequency-91*, *have-quant-91*, *temporal-quantity*, *date-entity*...
- New concepts for abstract events: “non-verbal” predication.
- New concepts for abstract entities: entity types are annotated for named entities and implicit arguments.
- Scope: *scope* concept to disambiguate scope ambiguity to facilitate translation of UMR to logical expressions (see sentence-level structure).
- Discourse relations: concepts to capture sentence-internal discourse relations (see sentence-level structure).

# Where do we find abstract eventive concepts?

Semantic type and information packaging (Croft 2001):

| | Reference | Modification | Predication |
|---|---|---|---|
| Entities | UNMARKED NOUNS | relative clauses, PPs on nouns | **predicate nominals, complements** |
| States | deadjectival nouns | UNMARKED ADJECTIVES | **predicate adjectives, complements** |
| Processes | **event nominals, complements, infinitives, gerunds** | **participles, relative clauses** | **UNMARKED VERBS** |

# Where do we find abstract eventive concepts?

- Sentence-level information packaging is not always predicational:
  - *I have a book* - “thetic”, “presentational”, all new information
  - *The book belongs to me* - “predicative”, possessee is known information
- AMR does not distinguish these meanings, UMR does only in typically “non-verbal” contexts:
  - Possession
  - Location
  - Object/Property predication

# Where do we find abstract eventive concepts?

- Languages use different strategies to express these meanings:
    - Overt predication: English *I have a book*

# Where do we find abstract eventive concepts?

- Languages use different strategies to express these meanings:
  - Juxtaposition: Tiwi

```
ngawa   mantani teraka
our     friend  wallaby
`Our friend has a wallaby,
lit. [as for] our friend, wallaby.'
```

# Where do we find abstract eventive concepts?

- Languages use different strategies to express these meanings:
  - Predicativized possessum: Yukaghir

```
pulun-die   jowje-n'-i
old.man-DIM net-PROP-3SG.INTR
`The old man has a net,
lit. The old man net-has.'
```

  - UMR trains annotators to recognize the semantics of these constructions and select the appropriate abstract predicate and its participant roles
  - UMR does not require alignment between concepts and words

# Sample abstract events

| Clause type | Predicate | ARG0 | ARG1 | ARG2 |
|---|---|---|---|---|
| thetic poss. | have-91 | possessor | possessum | |
| pred. poss. | belong-91 | possessum | possessor | |
| thetic loc. | exist-91 | location | theme | |
| pred. loc. | have-location-91 | theme | location | |
| property pred. | have-mod-91 | | theme | property |
| object pred. | have-role-91 | theme | ref. point | object category |
| equational | identity-91 | theme | equated referent | |

# Example abstract events

```
an-yetn-eye'          ko'o     vakka-hak        ah-angkok
2/3F-exist-V1.NFUT    1SG:PRO  cow-old/broken   1SG-POS
'I have a book.' lit. 'My book exists.'
(h / have-91
   :ARG0 (p / person
           :ref-person 1st
           :ref-number Singular)
    :ARG1 (v/ vakkahak 'book')
    :aspect State)
```

# Named entities in UMR are hierarchically organized

| Class | Type | Subtype |
|---|---|---|
| animal, plant, language, nationality, person, cultural-activity, award, food-dish, computer-program, variable | | |
| social-group | family, ethnic-group, regional-group, religious-group, clan | |
| | organization | international-organization, business, company, government-organization, political-organization, criminal-organization, armed-organization, academic-organization, association, sports-organization, religious-organization |

# Named entities in UMR are hierarchically organized

| Class | Type | Subtype |
|---|---|---|
| geographic-entity | ocean, sea, lake, river, gulf, bay, strait, canal, peninsula, mountain, volcano, valley, canyon, island, desert, forest | |
| celestial-body | moon, planet, star, constellation | |
| region | local-region, country-region, world-region | |
| geo-political-entity | city, city-district, county, state, province, territory, country | |
| facility | airport, station, port, tunnel, bridge, road, railway-line, canal, building, theater, museum, palace, hotel, worship-place, market, sports-facility, park, zoo, amusement-park | |
| vehicle | ship, aircraft, aircraft-type, spaceship, car-make | |

# Named entities in UMR are hierarchically organized

| Class | Type | Subtype |
|---|---|---|
| cultural-artifact | work-of-art, picture, music, literature, dance, show, broadcast-program | |
| | publication | book, newspaper, magazine, journal |
| event | incident, natural-disaster, earthquake, war, conference, game, festival, ceremony | |
| notational-system | writing-script, music-key, musical-note | |
| biomedical-entity | molecular-physical-entity, small-molecule, protein, protein-family, protein-segment, amino-acid, macro-molecular-complex, enzyme, nucleic-acid, pathway, gene, dna-sequence, cell, cell-line, species, taxon, disease, medical-condition | |

# Road Map

- Lexical resources and grammatical analysis is not available for many languages
- UMR aims to be available for semantic annotation of languages from the very beginning of analysis. It is therefore structured as a “Road Map”
    - Early stages of Road Map must not rely on availability of resources or analysis
    - Annotations at earlier stages must still be compatible with more fine-grained annotations at later stages

# Road Map

- Participant Roles:
  - Stage 0: General participant roles
  - Stage 1: Language-specific frame files
  - UMR-Writer allows for the creation of lexicon with argument structure information during annotation
- Morphosemantic Tests:
  - Stage 0: Identify one concept per word
  - Stage 1: Apply more fine-grained tests to identify concepts
- Annotation Categories with Lattices:
  - Stage 0: Use grammatically encoded categories (more general if necessary)
  - Stage 1: Use (overtly expressed) fine-grained categories
- Modal Dependencies:
  - Stage 0: Use simplified modal annotation
  - Stage 1: Fill in lexically based modal strength values

# Language-independent vs -specific participant roles

- Core participant roles are defined in a set of frame files (valency lexicon, see Palmer et al. 2005). The semantic roles for each sense of a predicate are defined:
  - E.g. boil-01: *apply heat to water*
    ARG0-PAG: *applier of heat*
    ARG1-PPT: *water*
- Most languages do not have frame files
  - But see e.g. Hindi (Bhat et al. 2014), Chinese (Xue 2006)
- UMR defines language-independent participant roles
  - Based on ValPaL data on co-expression patterns of different micro-roles (Hartmann et al., 2013)

# Language-independent roles: An incomplete list

| UMR Annotation | Definition |
|---|---|
| Actor | Animate entity that initiates the action |
| Undergoer | Entity (animate or inanimate) affected by the action |
| Theme | Entity (animate or inanimate) moving from one entity to another, spatially or metaphorically |
| Recipient | Animate entity that gains possession (or at least temporary control) of another entity |
| Force | Inanimate entity that initiates the action |
| Causer | Animate entity that acts on another animate entity to initiate the action |
| Experiencer | Animate entity that cognitively or sensorily experiences a stimulus |
| Stimulus | Entity (animate or inanimate) that is experienced by an experiencer |

# Language-independent vs language-specific participant roles

- Language-independent participant roles are assigned independent of grammatical relations in a language
  - [She]$_{actor}$ ate.
  - [She]$_{undergoer}$ fell.
- As lexical resources are developed for a language, annotations with language-independent participant roles can be linked to predicate-specific numbered argument roles:
  - E.g. Sanapaná Stage 0 – entoma: *eat*
    Actor: *eater*
    Undergoer: *food*
  - Sanapaná Stage 1 – entoma-01: eat
    ARG0: Actor
    ARG1: Undergoer

# Argument structure alternations

- Information-packaging alternations (e.g., passives) are not distinguished by the participant role annotation
- Semantic alternations (e.g., causatives, reflexives) are reflected in the participant role annotation

Berber (Guerssel 1986:52)

```
T-ttw-asy          tfirast.
3F.SG-DETR-pick.up  pear
'The pear was picked up.'

(t/ tttwasy-00 'pick up'
     :undergoer (t2/ tafirast 'pear'
          :ref-number Singular)
    :aspect Performance
    :modstr FullAff)
```

Kukama

```
nai          kurata-ta    churan=ui    uni=pu
grandmother  drink-CAUS   kid=PST      water=INS
'Grandmother made the kid drink the water.'

(k/ kuratata 'make drink'
     :causer (p/ person
           :ARG0-of (h/ have-rel-role-91
                :ARG2 (n/ nai 'grandmother'))
          :ref-number Singular)
     :actor (c/ churan 'kid')
          :ref-number Singular
     :undergoer (u/ uni 'water')
     :aspect Performance
     :modstr FullAff)
```

# How UMR accommodates cross-linguistic variability

- Not all languages grammaticalize/overtly express the same meaning contrasts:
  - English: *I* (1SG) vs. *you* (2SG) vs. *she/he* (3SG)
  - Sanapaná: *as-* (1SG) vs. *an-/ap-* (2/3SG)
- However, there are typological patterns in how semantic domains get subdivided:
  - A 1/3SG person category would be much more surprising than a 2/3SG one
- UMR uses lattices for abstract concepts, attribute values, and relations to accommodate variability across languages.
  - Languages with overt grammatical distinctions can choose to use more fine-grained categories

# Category Lattices

- Semantic categories are organized in “lattices” to achieve cross-lingual compatibility while accommodating variability
  - Lattices for Aspect, Modal Strength, Person, Number, Discourse Relations, Modification Relations