Contextual Vocabulary Acquisition:
A Computational Theory and Educational Curriculum

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Computational cognitive theory of <u>how to learn word meanings</u>

- From context
  - I.e., text + grammatical info + reader's prior knowledge
- With no external sources (human, on-line)
  - Unavailable, incomplete, or misleading
- Domain-independent
  - But more prior domain-knowledge yields better definitions
- "definition" = hypothesis about word's meaning
  - Revisable each time word is seen

Project Goals

- Develop & implement computational theory of CVA based on case studies of how people do it
- Translate algorithms into an educational curriculum
  - To improve CVA and reading comprehension of science, technology, engineering, math ("STEM")
- Use new case studies, based on the curriculum, to improve the algorithms & the curriculum

What does ‘brachet’ mean?

(From Malory's *Morte D'Arthur* [page # in brackets])

1. There came a white hart running into the hall with a white brachet next to him, and thirty couples of black hounds came running after them. [66]
2. As the hart went by the sideboard, the white brachet bit him. [66]
3. The knight arose, took up the brachet and rode away with the brachet. [66]
4. A lady came in and cried aloud to King Arthur, "Sire, the brachet is mine". [66]

10. There was the white brachet which bayed at him fast. [72]

18. The hart lay dead; a brachet was biting on his throat, and other hounds came behind. [86]

Cassie learns what "brachet" means:

Background info about: harts, animals, King Arthur, etc.
No info about: brachets
Input: formal-language version of simplified English

A hart runs into King Arthur's hall.
- In the story, B17 is a hart.
- In the story, B18 is a hall.
- In the story, B18 is King Arthur's.
- In the story, B17 runs into B18.

A white brachet is next to the hart.
- In the story, B19 is a brachet.
- In the story, B19 has the property "white".
- Therefore, brachets are physical objects.

(deduced while reading;
Cassie believes that only physical objects have color)

```
-->(defn_noun 'brachet)

(CLASS INCLUSION       = (PHYS OBJ)
 structure             = nil
 function              = nil
 actions               = (nil)
 ownership             = nil
 POSSIBLE PROPERTIES   = ((WHITE))
 synonyms              = nil)
```

I.e., a brachet is a physical object that may be white.

A hart runs into King Arthur's hall.
A white brachet is next to the hart.
The brachet bites the hart's buttock.

```
--> (defn_noun 'brachet)

(CLASS INCLUSION          = (ANIMAL)
 structure                = nil
 function                 = nil
 ACTIONS =
    ((POSSIBLE ACTIONS    = (BITE)))
 ownership                = nil
 POSSIBLE PROPERTIES      = ((WHITE))
 synonyms                 = nil)
```

A hart runs into King Arthur's hall.
A white brachet is next to the hart.
The brachet bites the hart's buttock.
The knight picks up the brachet.
The knight carries the brachet.

```
--> (defn_noun 'brachet)

(CLASS INCLUSION          = (ANIMAL)
 structure                = nil
 function                 = nil
 ACTIONS =
    ((POSSIBLE ACTIONS    = (BITE)))
 ownership                = nil
 POSSIBLE PROPERTIES      = ((SMALL WHITE))
 synonyms                 = nil)
```

A hart runs into King Arthur's hall.
A white brachet is next to the hart.
The brachet bites the hart's buttock.
The knight picks up the brachet.
The knight carries the brachet.
The lady says that she wants the brachet.

```
--> (defn_noun 'brachet)

(CLASS INCLUSION              = (ANIMAL)
 structure                    = nil
 function                     = nil
 ACTIONS =
     ((POSSIBLE ACTIONS       = (BITE)))
 ownership                    = nil
 POSSIBLE PROPERTIES          = ((SMALL VALUABLE WHITE))
 synonyms                     = nil)
```

A hart runs into King Arthur's hall.
A white brachet is next to the hart.
The brachet bites the hart's buttock.
The knight picks up the brachet.
The knight carries the brachet.
The lady says that she wants the brachet.
The brachet bays in the direction of Sir Tor.

[background knowledge: only hunting dogs bay]

```
--> (defn_noun 'brachet)

((A BRACHET IS A KIND OF   (DOG))
 ACTIONS =
       (POSSIBLE ACTIONS   = (BAY BITE))
 FUNCTION                  = (HUNT)
 structure                 = nil
 ownership                 = nil
 synonyms                  = nil)
```

I.e. A brachet is a dog that may bay & bite, and that hunts.

General Comments

- System's behavior ≈ human protocols
- System's definition ≈ OED's definition:
  = A brachet is "a kind of hound which hunts by scent"

Computational cognitive theory of how to learn word meanings from context (cont.)

- 3 kinds of words:
  - Unknown: ‘brachet’
  - Misunderstood: ‘(to) smite’
  - New use: ‘(to) dress’

- Initial hypothesis;
  Revision(s) upon further encounter(s);
  Converges to stable, dictionary-like definition;
  Subject to revision

Motivations & Applications

- Part of cognitive-science projects
  - Narrative text understanding
  - Syntactic semantics (contra Searle's Chinese-Room Argument)
- Computational applications:
  - Information extraction
  - Autonomous intelligent agents:
    - There can be no complete lexicon
    - Agent/IE-system shouldn't have to stop to ask questions
- Other applications:
  - L1 & L2 acquisition research
  - Computational lexicography
  - **** education: teaching reading ****

State of the Art

- Vocabulary Learning:
  - Some dubious contributions:
    - Useless "algorithms"
    - Contexts that include definition
  - Useful contribution:
    - (good) reader's word-model
      = updateable frame with slots & defaults
- Psychology:
  - Cues to look for (= slots for frame):
    - Space, time, value, properties, functions, causes, classes, synonyms, antonyms
  - Can understand a word w/o having a definition
- Computational Linguistics:
  - Systems need scripts, human informants, ontologies
    - Not needed in our system
  - CVA ≠ Word-Sense Disambiguation
    - Essay question vs. multiple-choice test

State of the Art: Vocabulary Learning

- Some dubious contributions:
  - Clarke/Nation 80: "algorithm"
    - (1) Find POS; (2) look at sentence;
      (3) look at context; **(4) guess meaning. !!**
  - Mueser 84: "Practicing Vocabulary in Context"
    - BUT: "context" = definition !!
- Useful contribution:
  - Elshout-Mohr & van Daalen-Kapteijns 81,87:
    - (good) reader's model of new word =
      updateable frame with slots & defaults

State of the Art: Psychology

- Sternberg et al. 83,87:
  - Cues to look for (= slots for frame):
    - Spatiotemporal cues
    - Value cues
    - Properties
    - Functions
    - Cause/enablement information
    - Class memberships
    - Synonyms/antonyms
- Johnson-Laird 87:
  - Word understanding ≠ definition
  - Definitions aren't stored

State of the Art: Computational Linguistics

- Granger 77: "Foul-Up"
  - Based on Schank's theory of "scripts"
  - Our system not restricted to scripts
- Zernik 87: self-extending phrasal lexicon
  - Uses human informant
  - Ours system is really "self-extending"
- Hastings 94: "Camille"
  - Maps unknown word to known concept in ontology
  - Our system can learn new concepts
- Word-Sense Disambiguation:
  - Multiple-choice test
  - Our system: essay question

Implementation

- SNePS (Stuart C. Shapiro & SNeRG):
  - Intensional, propositional semantic-network knowledge-representation & reasoning system
  - Node-based & path-based reasoning
    - I.e., logical inference & generalized inheritance
  - SNeBR belief revision system
    - Used for revision of definitions
  - SNaLPS natural-language input/output
  - "Cassie": computational cognitive agent

How It Works

- SNePS represents:
  - background knowledge + text information
    in a single, consolidated semantic network
- Algorithms search network for slot-fillers for definition frame
- Search is guided by desired slots
  - E.g., prefers general info over particular info,
    but takes what it can get

Noun Algorithm

Find or infer:

- Basic-level class memberships (e.g., "dog", rather than "animal")
  - else most-specific-level class memberships
  - else names of individuals
- Properties of Ns (else, of individual Ns)
- Structure of Ns (else …)
- Functions of Ns (else …)
- Acts that Ns perform (else …)
- Agents that perform acts w.r.t. Ns
  & the acts they perform (else…)
- Ownership
- Synonyms

Else do: "syntactic/algebraic manipulation"

- "Al broke a vase" → a vase is something Al broke
  - Or: a vase is a breakable physical object

Verb Algorithm

- Find or infer:
  - Predicate structure:
    - Categorize arguments/cases
  - Results of V'ing:
    - Effects, state changes
  - Enabling conditions for V
- Future work:
  - Classification of verb-type
  - Synonyms

- [Also: preliminary work on adjective algorithm]

Belief Revision

- Used to revise definitions of words with different sense from current meaning hypothesis
- SNeBR (ATMS; Martins & Shapiro 88):
  - If inference leads to a contradiction, then:
    1. SNeBR asks user to remove culprit(s)
    2. & automatically removes consequences inferred from culprit
- SNePSwD (SNePS w/ Defaults; Martins & Cravo 91)
  - Currently used to automate step 1, above
- AutoBR (Johnson & Shapiro, in progress)
  - Will replace SNePSwD

Educational Curriculum

- Use knowledge gained from computational CVA system …
  - To build & evaluate educational curriculum …
    - To enhance students' abilities to use deliberate CVA strategies …
      - In reading "STEM" texts.
- Use knowledge gained from CVA case studies to improve computational CVA system.

Research Methodology

- AI team:
  - Develop, implement, & test better computational theories of CVA
  - Translate into English for use by reading team
- Reading team:
  - Convert algorithms to curriculum
  - Think-aloud protocols
    - To gather new data for use by AI team
    - As curricular technique (case studies)
- Use Cassie to learn how to teach humans & use humans to learn how to teach Cassie

Problem in Converting Algorithm into Curriculum

- "A knight picks up a brachet and carries it away …"
- Cassie:
  - Has "perfect memory"
  - Is "perfect reasoner"
  - Automatically infers that brachet is small
- People don't always realize this:
  - May need prompting: How big is the brachet?
  - May need relevant background knowledge
  - May need help in drawing inferences
- Teaching CVA =? teaching general reading comprehension
  - Vocabulary knowledge correlates with reading comprehension

CVA & Science Education

- Original goal: CVA in & for science education
  - Use CVA to improve reading of STEM materials
- A side effect: CVA as science education
  - There are no ultimate authorities to consult
    - No answers in the back of the book of life!
    - As true for physics as for reading
  - ∴ Goal of education =
    - To learn how to learn on one's own
    - Help develop confidence & desire to use that skill
  - CVA as sci. method in miniature furthers this goal:
    - Find clues/evidence (gathering data)
    - Integrate them with personal background knowledge
    - Use together to develop new theory (e.g., new meaning)
    - Test/revise new theory (on future encounters with word)

Question (objection):

Why not use a dictionary?

Because:

- People are lazy (!)
- Dictionaries are not always available
- Dictionaries are always incomplete
- Dictionary definitions are not always useful
  - 'chaste' $=_{df}$ pure, clean /∴ "new dishes are chaste"
- Most words learned via incidental CVA, not via dictionaries

Question (objection):

Teaching computers ≠ teaching humans!

But:

- Our goal:
  - Not: teach people to "think like computers"
  - But: to explicate computable & teachable methods to hypothesize word meanings from context
- AI as computational psychology:
  - Devise computer programs that are essentially faithful simulations of human cognitive behavior
  - Can tell us something about human mind.
- We are teaching a machine, to see if what we learn in teaching it can help us teach students better.

Conclusion

Developing a computational theory of CVA,
which can become …

- a useful educational technique for improving [STEM] vocabulary and reading comprehension
- a model of the scientific method
- a useful tool for learning on one's own.

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