Metareasoning as an Integral Part of Commonsense and Autocognitive Reasoning

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Summary

- **SELF-AWARE AGENT DESIGN: Overview**
  - goals: explicit self-awareness
  - approach to KR&R: EL & EPILOG
  - architecture & the role of metareasoning

- **KR&R FEATURES CRUCIAL FOR METAREASONING**
  - “syntactic”, introspective, autocognitive reasoning

- **OTHER IMPORTANT ASPECTS OF KR&R**
  - normalization, inference graph, term evaluation, etc.

- **QA EXAMPLES**
  - quantitative, indexical, & descriptive QA
Self-aware agent design: Goals

**Perspective:** A self-aware agent is only as interesting as the things it knows and can do!

- **Explicit self-awareness**
  - *Human-like* world- and self-knowledge
  - *Transparent*: understandable KR, usable by general inference methods
  - *Communicative*: Dialogs about self & world
  - *Self-motivated, plan-driven*
Self-aware agent design: Approach to KR&R

Perspective: Human-like reasoning requires a KR as expressive as NL, & corresponding inference methods

- Episodic Logic (EL)
  - Events and situations
  - General quantification, modification, reification
  - Attitudes & autoepistemic knowledge
  - Metasyntactic devices (to be described)
**Self-aware agent design:**

**Architecture & the Role of Metareasoning**

**Perspective:** A self-motivated agent needs to plan continually, and use both object- & metalevel knowledge in planning and reasoning. (No uniform meta-control)

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Continual Planner
"Life plan"
- Step1
- Step2
-....

KB:
- Curr. state
- General knowledge
- Episodic knowledge

EPILOG:
- Reasoning (including meta)
- Phys. action (listening, Speaking)

Learning: Acquiring knowledge, abstracting plans
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Role of Metareasoning, in more detail

• **Reasoning about the syntax of formulas**
  – Answer descriptive questions (e.g. *What do you know about the appearance of pigs?*)
  – Decide what special procedural method may be applicable to a given task
  – Produce answers in the desired format (e.g., giving one’s age in years, not as difference in dates)

• **Positive and Negative introspection**
  (e.g., knowing/inferring how much/little we know about a thing, kind of thing, or topic; descriptive QA)

• **Autocognitive reasoning**
  (e.g., “*Did the phone ring?*” – I know I would have heard it, if it rang; how we perceive, learn, etc.)
Epilog's features crucial for Meta-reasoning
Substitutional Quantification
Quasi-Quotation

• Classify syntactic elements
  ['= (Commutative (EL-Predicate))]

• Formal treatment of meaning postulates
  \( (\forall x (\forall_{\text{pred-modifier}} m ['m (\text{Monotonic EL-pred-mod})]
  \forall_{\text{pred}} p [x (m p)] [x p])) \)

• Allows selection of special routines based on axioms on their effects
  \( (\forall_{\text{wff}} w ['w \text{ Without-free-vars}]
  [[(\text{APPLY 'knownbyme? 'w)} = 'yes] <=>
  [(\text{That w) Knownbyme}]] \)
Substitutional Quantification
Quasi-Quotation

• Wff Parser
  – allow for substitutional quantifiers and quotation in EL formulas

• Unification
  – unify a metavariable with an expression of a particular type: $w_{\text{wff}}$ with $((K (\text{plur Apple})) \text{ Red})$
Recursive-QA

- Implements Kaplan and Schubert's ASK-TELL mechanism
  - difference between knowing and being able to infer
- Implemented as ability to start a QA process inside another QA process
- Use of axioms to let EPILOG decide when to start a QA process:
  \[(\text{All}_{w} w \ [\text{w Without-free-vars}]
   \ [(\text{APPLY 'knownbyme? 'w) = 'yes} \iff
   [(\text{That w) Knownbyme}])\]
Other important aspects of KR&R in EPILOG
Normalization

• FOL normalization not possible in EL
  – intensional operators (modifiers, reifiers, etc.),
    generalized quantifiers (Most, Many, etc.)

• Based on rewrite engines
  – set of rules that state preconditions and effects
  – applied till the input formula is changed

• currently there are 19 rules
  – move negation inward, cluster AND/ORs, remove
    trivial tautologies, move episodic operators
    inward, skolemize, etc.
Inference Graph

• Inference generates a tree
  – start with 2 subgoals (proof, disproof)
  – pick a subgoal to process (agenda):
    • retrieve knowledge, do inference, produce new subgoals
    • apply simplifications: split, assumptions, special handling
    • add to agenda what's left
  – loop detection/duplication handling (graph)
Multiple Answers

• Required for WH questions
  – propagate answers from the leaves up to the initial question
    • wait for answers from siblings
    • unifier merging and variable renaming
  – recognize duplicated answers
    • unifier and knowledge used
  – user selectable termination criterion
Term Evaluation

• Simplify terms
  – e.g.: How old are you?
    The difference in years between 1\textsuperscript{st} Jan 1993 and now.

• Pose a question ($\text{Wh } x \ [x = \text{ term}]$) and collect all answers that are simpler than term
Examples

• How old are you?
• What's your name?
• What do you know about the appearance of pigs?
How old are you?

- Question:
  \[(\text{Wh } x \ (\text{Wh } e \ [e \text{ At-about Now0}]
  \ [\text{Epilog Has-age-in-years } x] ** e))\]

- Answer:
  \[e = (\text{Fn1 Now0})\]
  \[x = (\text{Diff-in-years} \ (\text{Date 1 1 1993 0 0 0})
  \ (\text{Time-of} \ (\text{Fn1 Now0}))\]
How old are you?

• Evaluate:
  \[ x = (\text{Diff-in-years} \ (\text{Date} \ 1 \ 1 \ 1993 \ 0 \ 0 \ 0) \ (\text{Time-of} \ (\text{Fn1} \ \text{Now0}))) \]

• Start QA process for question:
  \[(\text{Wh} \ x \ [x = (\text{Diff-in-years} \ (\text{Date} \ 1 \ 1 \ 1993 \ 0 \ 0 \ 0) \ (\text{Time-of} \ (\text{Fn1} \ \text{Now0}))))] \]

• Use knowledge produced while answering QA:
  \[(\text{Fn1} \ \text{Now0}) \ \text{At-about} \ \text{Now0}] \]

• Axioms:
  \[(\forall_{\text{term}} \ x \ (\forall_{\text{term}} \ x1 \ ['x1 \ \text{Absolute-time-point}] \ (\forall_{\text{term}} \ x2 \ ['x2 \ \text{Absolute-time-point}] \ [\ ['x = (\text{APPLY} \ '\text{diff-in-years?} \ 'x1 \ 'x2)] \Rightarrow \ [x = (\text{Diff-in-years} \ x1 \ x2)]]))] \]
What's your name?

• Question:
  \((\exists \, e_0 \ [e_0 \ \text{At-about} \ \text{Now0}] \ \land \ [\text{Epilog Have} \ z])\)
  \((\exists \, y \ [y \ \text{Thing}] \ [y \ (\text{Be} \ (L \ x \ [x = z]))])) \)** e0]

• Meta-knowledge used while normalizing:
  ['Thing EL-type-pred]
  ['Name EL-type-pred]
What do you know about the appearance of pigs?

Assume that predicates have been assigned metalevel topics in a topic hierarchy:

For physical objects (simplified):

- **appearance**
  - shape (e.g., thick-bodied, tapered, ..)
  - coloring (e.g., pink, striped, mottled,..)
  - texture (e.g., smooth, prickly, ..)

- **structure**
  - parts (e.g., part-of, top-of, ..)
  - connections (e.g., attached-to, inside, ..)

- **existence**
  - genesis (e.g., be-born, be-manufactured, be-built, ..)
  - destruction (e.g., die, be-eaten, explode, ..)

- **behavior**
  - motion (e.g., run, spin, fall, ..)
  - self-maintenance (e.g., eat, groom, sleep, ..)
  - social-behavior (e.g., converse, fight, invite, ..)

- **function**
  - transport
  - nourish
  - ..
What do you know about the appearance of pigs?

- **Question:**
  \[(Wh \ x \ [x \ \text{Appearance-fact-about} \ (K \ (\text{Plur pig}))])\]

- **Answer:**
  \[(\text{That} \ [(K \ (\text{Plur Pig})) \ \text{Thick-bodied}])\]

- **Meta-knowledge used:**
  \['\text{Thick-bodied Appearance-pred}'\],
  \[(\forall \ \text{pred} \ p \ ['p \ \text{Appearance-pred}]\)
  \[(\forall \ x \ [x \ p] \ [(\text{That} \ [x \ p]) \ \text{Appearance-fact-about} \ x])]\)
Conclusion

• Explicit self-awareness & commonsense reasoning require integrated object-level / meta-level inferences
• Such inferences can be effectively realized in a highly expressive representation that is “language-like” (EL $\rightarrow$ EPILOG).