User-Oriented Solving and Explaining of Natural Language Logic Grid Puzzles

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https://bartbog.github.io/zebra/

Holy Grail-ish

From *human-level* problem specification,
to *human-level* solving and explanation.

↓ *applied on* ↓

Logic Grid Puzzles[1]

How ?

Clues in Natural Language → Logic Grid → Visual explanation of reasoning steps

[1]https://freuder.wordpress.com/pthg-19-the-third-workshop-on-progress-towards-the-holy-grail/

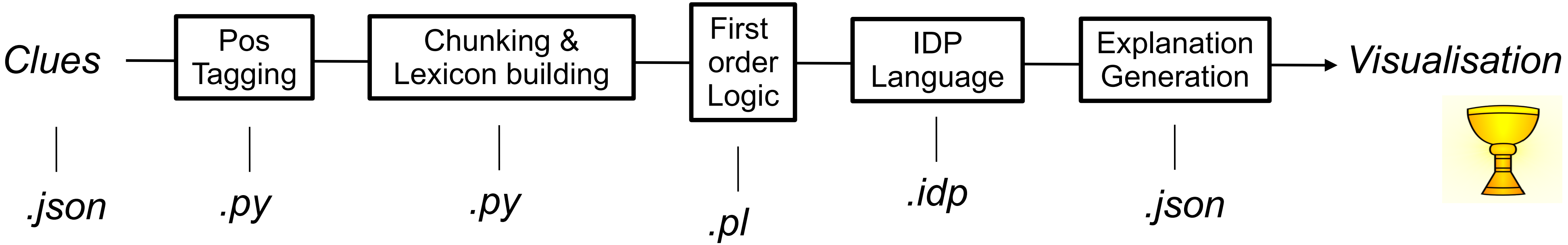
Zebra Tutor, a Holy Grail

“From *human-level* problem specification to *human-level* solving and explanation.”

Our design choices:

- Input: natural language (with semi-automated processing)
- Reasoning: Blackburn & Bos semantic parsing + IDP solver
- Output: **visual** explanation
  - Abstractions: grid visualisation and clues
  - Ordering of reasoning steps: by 'mental effort',
  - in practice: order by number of clues used, then by number of *facts* used

HolyZebra approach



POS tagging

In: Natural Language sentences

Out: Part-Of-Speech tagged words

Technically: NLTK's Perceptron tagger with the Penn Treebank POS set

"The patient who was prescribed Enalapril is not Heather”[1]

"The	patient	who	was	prescribed	Enalapril	is	not	Heather”[1]
DT	NN	WP	VBD	VBN	NN	VBZ	RB	NNPN

[1]Output : (the, DT), (patient, NN), (who, WP), (was, VBD), (prescribed, VBN), (enalapril, NN), (is, VBZ), (not, RB), (heather, NNPN).

Chunking and lexicon building

In: POS tagged sentences

(the, DT), (patient, NN), (who, WP), (was, VBD), (prescribed, VBN), (enalapril, NN), (is, VBZ), (not, RB), (heather, NNPN)

Mid: Chunking

(the, *det*), (patient, *noun*), (who, *relpro*), ((was, prescribed), *tvGap*), (enalapril, *pn*), ((is, not), *cop*), (heather, *pn*)

Out: Lexicon for our B&B grammar

…
noun([patient], [patients]),
pn([heather]),
pn([enalapril]),
tvGap([was, prescribed], [for, their, heart, condition], [prescribe]),
…

Chunking and lexicon building

In: POS tagged sentences

Mid: Chunking

Out: Lexicon for our B&B grammar (next slide)

Old school NLP approach:

- regular expressions
- semi-automated

Difficulty:

- custom vocabulary per puzzle
- word-play by authors

To logic

Input: *Lexicon* and *Grammar*

Output: Discourse Representation Theory

Blackburn and Bos framework as a base:

- Defined grammar based on 10 other puzzles, which includes :
  - Template sentences specific to logic grid puzzles
  - alldifferent rules : :*"Of X,Y and Z, one is..."*
  - Numerical comparisons (*"John scored 3 points higher than Mary"*), …
- Extended Blackbrun & Bos framework to reason about types:
  - Each entity (John, points) has a type
  - Some relations (scored, has more, received) are synonyms: types allow detecting them

To IDP language

Input: Logical Representation (Discourse Representation Theory)

Output: IDP Puzzle specification

1. Compute interpretation of different types
   - Type deduction from grid (if available)
   - Type inference from sentence(s).

"The Englishman **smokes** cigarettes"

"The person who owns a dog does not **smoke** cigars"

To IDP language

Input: Logical Representation (Discourse Representation Theory)

Output: IDP Puzzle specification

1. Compute interpretation of different types
   - Type deduction from grid (if available)
   - Type inference from sentence(s).
     - ! also supports missing entities (e.g. the zebra)

To IDP language

Input: Logical Representation (Discourse Representation Theory)

Output: IDP Puzzle specification

1. Compute interpretation of different types

2. Build Vocabulary
   - Types and relation for each transitive verb or preposition
   - Ensure at least 1 relation between each 2 types
     - ! Important for explanation

“John lives in the red house” ⧓ *LivesIn*(<person>, <house>)

To IDP language

Input: Logical Representation (Discourse Representation Theory)

Output: IDP Puzzle specification

1. Compute interpretation of different types

2. Build Vocabulary

3. Construct IDP Theories:
    1. Translate each clue into IDP language
    2. Add implicit constraints present in logic grid puzzles :
        - Synonymy
        - Bijection (lives_in / owns_house)
        - Transitivity (rel1(A,B) rel2(B,C) → rel3(A,C))

To IDP language

Input: Logical Representation (Discourse Representation Theory)
Output: IDP Puzzle specification

1. Compute interpretation of different types
2. Build Vocabulary
3. Construct IDP Theories:
4. Solving the Puzzle using the IDP solver
   (ASP / model expansion / lazy clause generation-like solver)

To explanations

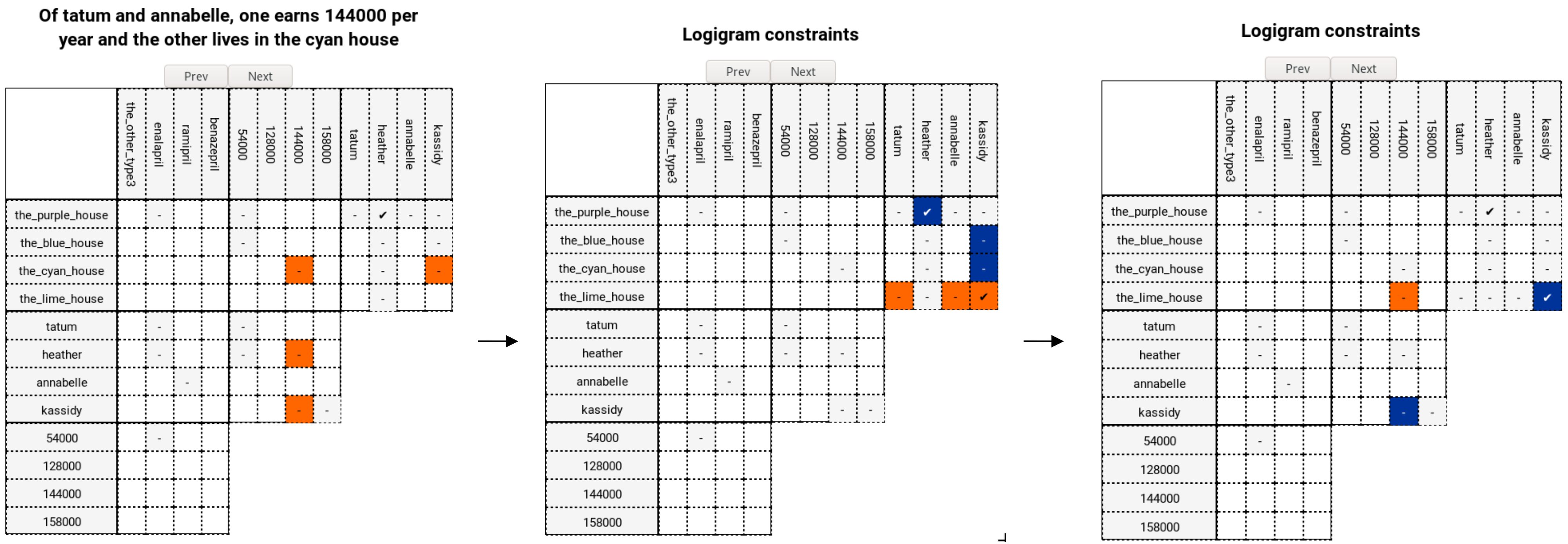
Ordering of reasoning steps by mental effort required

get_reasoning_step(S: *current partial assignment):*

- Until a solve leads to propagation (a more strict partial assignment):
  - Try: solve S + all implicit constraints
  - For n=0..|clues|, for all subsets of clues of size *n*:
    - Try: solve S + the constraints from the subset of clues
    - *Break* if it lead to propagation
- For each *literal* that was assigned during propagation:
  - Compute minimal partial assignment S' needed to derive the literal
  - → **the S' is the UNSAT core when negating the *literal***
  - Store (S', clues used, literal)
- **return** (S', clues, literal) with smallest S'

Clues — Pos Tagging — Chunking & Lexicon Building — First-Order Logic — IDP Language — Explanation Generation → ***Visualisation***

Visualisation[1]



[1] https://bartbog.github.io/zebra/

Related work

Solving Logic Puzzles : From Robust Processing to Precise semantics

Iddo Lev[1], Bill MacCartney[1], Christopher D. Maning[2], and Roger Levy[2],
Workshop on Text Meaning and Interpretation, January 2004
[1]Department of Computer Science, Stanford University *{iddolev|wcmac|manning}@cs.stanford.edu*
[2]Department of Linguistics, Stanford University *rog@stanford.edu*

Similarities

Solver : FOL *reasoner*

Semantic Logic language

Compositional semantics : Blackburn&Bos

Differences

Data : *GRE[1]* and *LSAT[2]* multiple-choice logic puzzles with 1 correct answer:

Backtracking ambiguities : ranking of possible output representations

Statistical parser

Generic semantic rules applicable to other problem settings

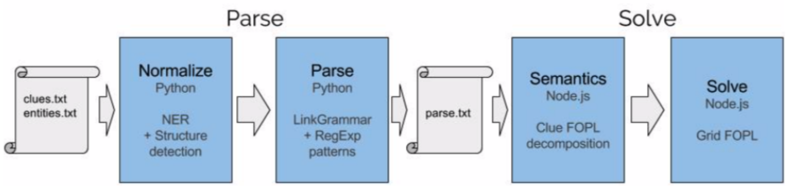
Use of Theorem prover and model builder to solve problem (parallel execution, first to solve the problem).

[1]**G**raduate **R**ecord **E**xam, [2]**L**aw **S**chool **A**dmission **T**est

Related work

LogicSolver – Solving Logic Grid Puzzles with POS Tagging and First-Order Logic.

Ross Nordstram, Masters Project, Decembre 2016,
University of Colorado *rnordstr@uccs.edu*



Key Differences

Goal : POS Tagging, First-order Logic

Puzzler as a base reasoner system

Normalization

- NER (named entity recognition)
- Structure detection

Parsing

- Link Grammar Parser
- Regex (clues) pattern matching

Main Problems

Hard-coded clue structure knowledge to identify comparisons (regex).

Solver

Hard-coding of less vs greater comparisons and comparison contexts

Ex1:

Taller must apply to entity type of “height” or “ distance”

Ex2:

Jeffery’s pack is larger than the Grennel pack

Conclusion

From *human-level* problem specification
to *human-level* solving explanation.

Our design choices:

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- ordering: by mental effort, proxy = nr of literals used

Can also serve as 'help' function when user is stuck

Conclusion and future work

From *human-level* problem specification
to *human-level* solving explanation.

Our design choices:

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Can also serve as 'help' function when user is stuck

- Better NLP: statistical techniques?
- Explanation orderings and proxies for 'mental effort'
- Explanation abstractions, e.g. important parts of clue
- Other puzzle explanations
- Applicability in industrial problems, e.g. scheduling?