Playing with AVATAR
How to play with AVATAR

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The 1st Vampire Workshop
Overview

1 Introduction

2 Reviewing AVATAR

3 The variables

4 How to evaluate

5 Results

6 Conclusion
Introduction

In this talk we will:

- Briefly recall what the AVATAR architecture is
- List the parameters that control its behaviour
  - (and what effects they have)
- Discuss how we should evaluate these kinds of frameworks
- Present results of our experimental evaluation

Work in progress!
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AVATAR

- **Input:**
  \[ p(a), \ q(b), \ \neg p(x) \lor \neg q(y) \]

- **Repeat**
  - **FO:** Process new clauses
    - split clauses into components
  - **SAT:** Construct model
  - **FO:** Use model (do splitting)
  - **FO:** Do FO proving
    - Process refutation

Components

**Components**
AVATAR

- Input:
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AVATAR

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\[ p(a), \quad q(b), \quad \neg p(x) \lor \neg q(y) \]

Repeat

- **FO: Process new clauses**
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\[ p(a) \mid \{\} \]
AVATAR

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\[
\begin{align*}
\text{FO} & \quad \text{SAT} \\
p(a) | \{\} \\
q(b) | \{\}
\end{align*}
\]
AVATAR

- **Input:**
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\[ \begin{align*}
\text{FO} & : p(a) \mid \{\} \\
\text{SAT} & : q(b) \mid \{\} \\
\text{Components} & : \\
1 & \mapsto \neg p(x) \\
2 & \mapsto \neg q(y)
\end{align*} \]
AVATAR

- **Input:**
  
  \[ p(a), q(b), \neg p(x) \lor \neg q(y) \]

- **Repeat**
  
  - FO: Process new clauses
    
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  - SAT: Construct model
  - FO: Use model (do splitting)
  - FO: Do FO proving
    
    - Process refutation

\[
\begin{array}{c|c}
\text{FO} & \text{SAT} \\
\hline
p(a) & \{\} \\
q(b) & \{\} \\
1 \lor 2 & \\
\end{array}
\]

Components

\[
1 \mapsto \neg p(x) \\
2 \mapsto \neg q(y)
\]
AVATAR

- **Input:**
  
  \[ p(a), \ q(b), \neg p(x) \lor \neg q(y) \]

- **Repeat**
  
  - **FO:** Process new clauses
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  - **FO:** Use model (do splitting)
  
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    - Process refutation

\[ \begin{align*}
  \text{FO} & \quad \text{SAT} \\
  p(a) & | \{\} \\
  q(b) & | \{\} \\
  \neg p(x) & | \{1\}
\end{align*} \]

Components

\[ \begin{align*}
  1 & \leftrightarrow \neg p(x) \\
  2 & \leftrightarrow \neg q(y)
\end{align*} \]
AVATAR

- **Input:**
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- 2 \mapsto \neg q(y)
AVATAR

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<table>
<thead>
<tr>
<th>FO</th>
<th>SAT</th>
</tr>
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<tbody>
<tr>
<td>( p(a) \mid {} )</td>
<td>( 1 \lor 2 )</td>
</tr>
<tr>
<td>( q(b) \mid {} )</td>
<td>( \neg 1 )</td>
</tr>
<tr>
<td>( \neg p(x) \mid {1} )</td>
<td></td>
</tr>
<tr>
<td>( \bot \mid {1} )</td>
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**Components**

1 \( \mapsto \neg p(x) \)
2 \( \mapsto \neg q(y) \)
AVATAR

- **Input:**
  
  \[ p(a), \; q(b), \; \neg p(x) \lor \neg q(y) \]

- **Repeat**
  
  - **FO:** Process new clauses
    
    - split clauses into components
  
  - **SAT:** Construct model
  
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- **FO SAT**

  - \( p(a) \mid \{\} \)
  
  - \( q(b) \mid \{\} \)
  
  - \( \neg p(x) \mid \{1\} \)
  
  - \( \bot \mid \{1\} \)

- **Componets**

  - \( 1 \mapsto \neg p(x) \)
  
  - \( 2 \mapsto \neg q(y) \)

- **Process refutation**

  - \( 1 \lor 2 \)
  
  - \( \neg 1 \)
AVATAR

- **Input:**
  \[ p(a), \; q(b), \; \neg p(x) \lor \neg q(y) \]

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### Components

| 1 ➡️ \( \neg p(x) \) |
| 2 ➡️ \( \neg q(y) \) |
Input:

\[ p(a), \ q(b), \ \neg p(x) \lor \neg q(y) \]

Repeat

- **FO**: Process new clauses
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- **SAT**: Construct model
- **FO**: Use model (do splitting)
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**Components**

\[
1 \mapsto \neg p(x) \\
2 \mapsto \neg q(y)
\]

**FO**

\[
\begin{align*}
p(a) \mid \{\} \\
q(b) \mid \{\} \\
\neg p(x) \mid \{1\} \\
\bot \mid \{1\} \\
\neg q(y) \mid \{2\} \\
\bot \mid \{2\}
\end{align*}
\]

**SAT**

\[
1 \lor 2 \\
\neg 1
\]
AVATAR

- **Input:**
  \[ p(a), \; q(b), \; \neg p(x) \vee \neg q(y) \]

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\]

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\[\begin{array}{ll}
\text{FO} & \text{SAT} \\
\hline
p(a) \mid \{\} & 1 \lor 2 \\
q(b) \mid \{\} & \neg 1 \\
\neg p(x) \mid \{1\} & \neg 2 \\
\bot \mid \{1\} & \\
\neg q(y) \mid \{2\} & \\
\bot \mid \{2\} & \\
\end{array}\]

**Components**

\[\begin{array}{c}
1 \leftrightarrow \neg p(x) \\
2 \leftrightarrow \neg q(y) \\
\end{array}\]
AVATAR

- **Input:**
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- **Refutation**
  - From the SAT solver as we cannot construct a model

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<tr>
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<td></td>
</tr>
<tr>
<td>( \neg q(y) \mid { 2 } )</td>
<td></td>
</tr>
<tr>
<td>( \bot \mid { 2 } )</td>
<td></td>
</tr>
</tbody>
</table>

**Components**

| 1 | \( \rightarrow \neg p(x) \) |
| 2 | \( \rightarrow \neg q(y) \) |
Important points

- Components are always named consistently (up to variants)
- An inference between two clauses with assertions takes the union of those assertions:

\[
\frac{c_1 \mid a_1 \quad c_2 \mid a_2}{d \mid (a_1 \cup a_2)}
\]

- Removal of redundant clauses is conditional in general:
  - assume that \( c_2 \) is subsumed by \( c_1 \) for clauses \( c_1 \mid a_1 \) and \( c_2 \mid a_2 \)
  - If \( a_1 \subseteq a_2 \)
    - Then whenever \( c_1 \mid a_1 \) is backtracked, then \( c_2 \mid a_2 \) must be also, as an assertion in \( a_1 \) is retracted, which must also be in \( a_2 \)
    - Therefore, we can remove \( c_2 \mid a_2 \)
  - otherwise (\( a_1 \not\subseteq a_2 \))
    - Later, if an assertion in \( a_2/a_1 \) is retracted then \( c_1 \mid a_1 \) would be backtracked, but \( c_2 \mid a_2 \) would not be
    - Therefore, we conditionally remove (freeze) \( c_2 \mid a_2 \)
    - Then, if \( c_1 \mid a_1 \) is later removed we must add (unfreeze) \( c_2 \mid a_2 \)
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Adding components (nonsplittable clauses)

- If we cannot split a clause into components what do we do?
  - Just add it anyway - it might be useful later!
  - Only add it as a component if it has assertions (dependencies) i.e.
    - If we derive $q(x) \lor p(x)|\{2, 4\}$ we would add $\neg 2 \lor \neg 4 \lor 8$ (for fresh 8)
    - Helps if 8 is derived again later
  - Only add it as a component if it is a known component i.e.
    - We previously added $2 \lor 4$ for $r(y) \iff 2$ and $q(x) \lor p(x) \iff 4$
    - We then derive $q(x) \lor p(x)$ and add 4
    - The SAT solver must always choose 4 - simplifying $2 \lor 4$
  - Don’t add it
Adding components (ground components)

- If a component is ground it is safe to introduce a name for its negation (not safe for non-ground)

- If we have $p(x) \lor q(a)$ and $\neg p(x) \lor \neg q(a)$ we can add
  
  $1 \lor 2$ and $3 \lor 4$

  but it is better to add

  $1 \lor 2$ and $3 \lor \neg 2$

- This is something we do not play with, as previous experiments showed that it was consistently a good idea

- Note that a ground component will be a literal
Constructing a model

- In AVATAR the SAT solver is a black box that is allowed to construct any valid model. There are two things we can consider:
  - How quickly a model can be constructed
  - What model is constructed

- It is obvious that the model produced has a very large effect on the exploration of the search space.

- We consider two SAT solvers:
  - A native (two watched literals) solver
  - lingeling (with relatively default options)

- We also consider a buffering optimisation that buffers a clause if, either:
  - it contains a fresh variable that can be made true, or
  - it is already true in the model

  This may lead to fewer calls to the SAT solver, but will also lead to a different model.
Using a model

- As mentioned above, we do not need the whole model
- If we use a partial model we
  - Have to pay to minimise the model
  - But, we potentially add fewer FO clauses and do less freezing/unfreezing

- Choices:
  - Total model
  - Minimised model - a partial model that satisfies all added clauses
  - Minimised model for split clauses - satisfy split clauses only

- Note - partial model is a sub-model of the total one

- If a component was previously asserted, but is now don’t care (not in the partial model) we can either
  - eagerly remove it, or
  - leave it there... it might be asserted again later
An overview of the relevant options

- **Adding components**
  - `ssplitting_nonsplittable_components`
    - When to add a component that is not splittable
    - `known`, `all`, `all_dependencies`, `none`

- **Constructing a model**
  - `sat_solver`
    - Which sat solver is used to construct the model
    - `lingeling` or `vampire`, with buffering or not

- **Using a model**
  - `ssplitting_model`
    - We can minimise the model to reduce the number of components asserted in the FO part
    - `total`, `min_all`, `min_sco`
  - `ssplitting_eager_removal`
    - When using a non-total model we can eagerly remove components no longer mentioned by the model
    - `on`, `off`
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How should we evaluate?

- CASC mode makes use of 47 different (still valid) options
- Many of these have multiple values (some are continuous)
- If we stick only to values selected in CASC mode we have 493,748,224 possible combinations (some of which will not be valid)

- TPTP v6.0.0 has 16,004 FOF and CNF problems

- Giving one minute per experiment that takes 1,500 millennia per value we want to compare
  - That’s 144,000 millennia for the experiments here...
  - To finish now we should have started at the end of the Jurassic period

- We need to consider what we are looking for...
Directly comparing options

- If we want to generally compare different values for an option we need to systematically run through the same experiments for each value.

- Massive search space requires us to select a subset of options or problems
  - Select subset of options
    - May miss the best strategies
  - Select subset of problems
    - May miss the easy/hard problems
  - Probably need to do both to have a reasonable search space

- Alternatively, we could use the CASC-mode approach that attempts multiple strategies, but
  - This suffers from similar restrictions i.e. the results are not generalisable from the chosen strategies.
  - Additionally it is biased as the default values for all of these options were included in the CASC-mode training... so are more likely to be successful.
Observation: A CASC-mode-like approach makes use of many strategies. Therefore, if a strategy can be shown to perform well for some problems, its performance on other problems does not matter.

If our aim is to solve new problems or solve problems faster then we want to identify cases where new options lead to these interesting cases.

We can randomly select a strategy, a problem and an option to experiment with. We then vary the values for this option and check whether the result is interesting.

However, our results are not generalisable.
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Our experiments

- **Systematic**
  - Use CASC13 problems
  - Use default options

- **Random**
  - Construct an experiment by randomly selecting
    - A problem
    - A set of options
    - An experimental option
  - Vary the value for the experimental option
  - However - currently keep other experimental options as default

- **These results**
  - are not complete
  - can only be generalised within a certain context
  - are not very exciting
SAT solver

Out of 300 problems

- buf-vampire
- buf-lingeling
- vampire
- lingeling
Nonsplittable Components

Out of 1665 problems

- known
- none
- all-dependent
- all

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How to play with AVATAR
Nonsplittable Components

Out of 1682 problems, cross of Time elapsed

none
known

How to play with AVATAR
Nonsplittable Components

Out of 1670 problems, cross of SAT solver-percent

known

0 10 20 30 40 50 60 70 80 90 100

all
Model minimisation

Out of 300 problems

- vampire,total
- lingeling,total
- vampire,min-all
- lingeling,min-all
- vampire,min-sco
- lingeling,min-sco

Reger, G

How to play with AVATAR
Model minimisation

Out of 1934 problems

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Reger, G

How to play with AVATAR
Eager removal

Out of 1662 problems
Unanswered questions

- Can we encourage the SAT solver to construct a model that leads to ‘nice’ clauses being added to the FO part?
  - i.e. light, small clauses rather than heavy, long ones

- What makes a nice model?
  - How constrained is the model (can we make any difference?)
  - How does the constructed model interact with selection?

- Can we encourage the SAT solver to construct a model with a minimal difference from the previous model?
  - Beyond phase saving and Vampire’s backtrack-to-last-valid-choice

- Would giving the SAT solver more information help?
  - i.e. add a clause if one component subsumes another

- Can we do more from a refutation with assumptions?
  - i.e. minimise them, collect multiple refutations in one FO run
Conclusions

- AVATAR is fun
- There are lots of things we can tweak
- Running experiments is difficult
- Our results were not interesting - maybe we asked the wrong questions