Local Closed World Semantics: Grounded Circumscription for OWL

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Outline

- Local Closed World Assumption
- Grounded Circumscription Semantics
- Contribution
- Decidability
- Algorithms
- Conclusion

OWA and CWA

- Open World Assumption (OWA)
  - If a statement is not known to be true, it is not assumed to be false.
  - Knowledge is considered incomplete.
  - OWL
- Closed world assumption (CWA)
  - If there is no proof for a statement to be true, it is false.
  - Knowledge is assumed to be complete.
  - Logic programming, databases etc.

OWL Example

- KB =

$$\begin{array}{c} Paper(paper1) \\ Paper(paper2) \\ hasAuthor(paper1, author1) \\ hasAuthor(paper1, author2) \\ hasAuthor(paper2, author3) \\ \top \sqsubseteq \forall hasAuthor.Author \end{array}$$

- $\neg$hasAuthor(paper1, author3) is not a consequence.
- Because of OWA, can't rule out hasAuthor(paper1, auther3)
- ($\leq$2 hasAuthor.Author)(paper1) is not a consequence.

OWL Example

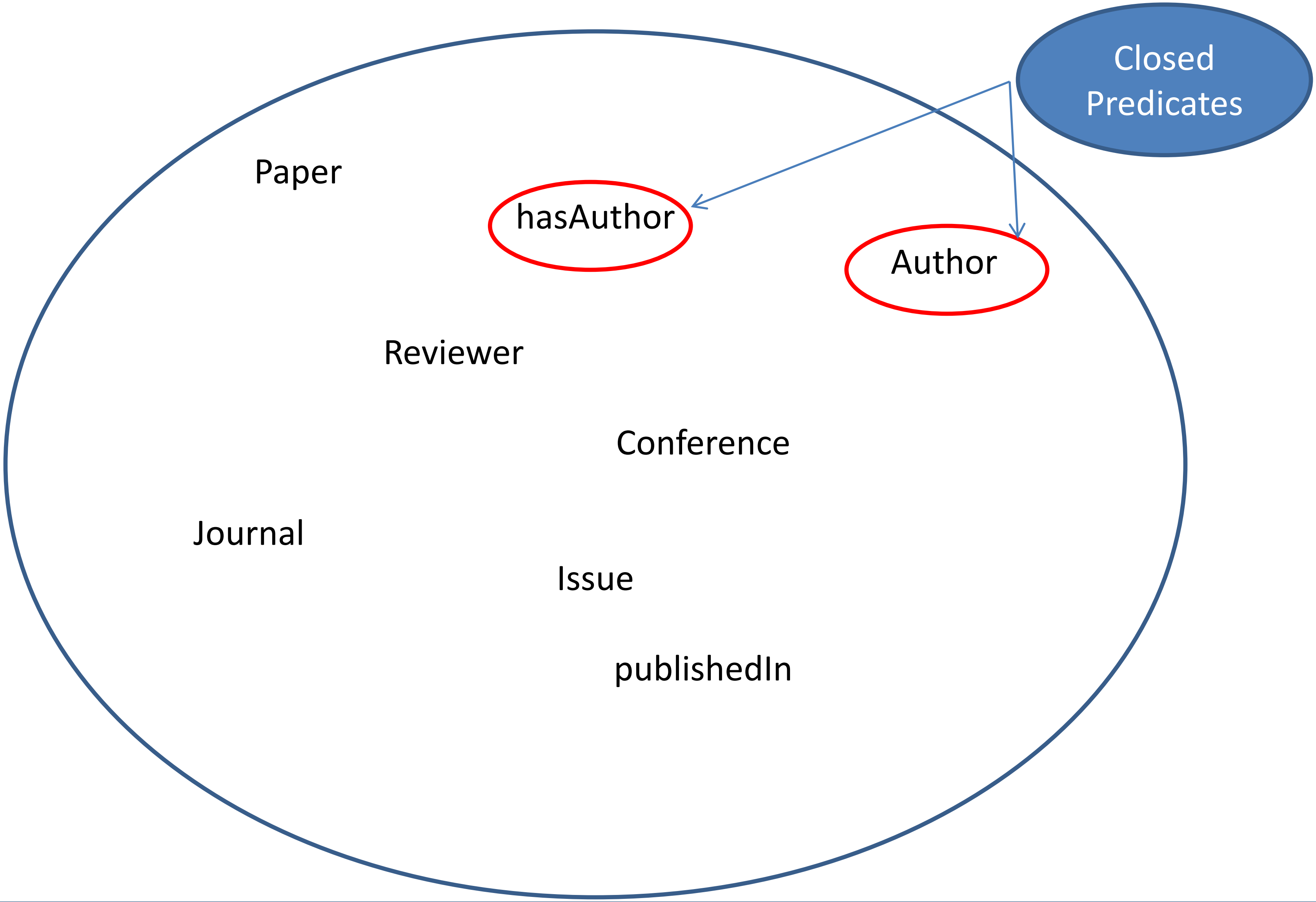
- KB =

Paper(paper1)
Paper(paper2)
hasAuthor(paper1, author1)
hasAuthor(paper1, author2)
hasAuthor(paper2, author3)
$\top \sqsubseteq \forall$hasAuthor.Author

There is a Model in which author3 is an author of paper1.

- $\neg$hasAuthor(paper1, author3) is not a consequence.
- Because of OWA, can't rule out hasAuthor(paper1, auther3)
- ($\leq$2 hasAuthor.Author)(paper1) is not a consequence.

Local Closed World



Solution?

- Local closed world Assumption
  - Combination of OWA and CWA.
  - Allow ontology engineers to close parts of the KB.
  - E.g. We can mark the class Author and the property hasAuthor as closed in the last example.
  - $\neg$hasAuthor(paper1, author3)
  - ($\leq$2 hasAuthor.Author)(paper1)

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Circumscription

- Circumscription for FOL [McCarthy 80]
- Minimisation: Extension of minimized predicates as small as possible.
- $Circ_{CP}$(KB), Circumscription Pattern (M,V,F)
- Circumpscription in DLs [Bonatti, Lutz, Wolter: JAIR 2009]

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Circumscription

- Preference relation $<_{CP}$ on Interpretations $I = (\Delta^I, \cdot^I)$
- Choose the preferred model. i.e minimal.

comparing interpretations by their extensions for minimized predicates

$\mathcal{I} <_{CP} \mathcal{J}$ if for two interpretations $\mathcal{I}$ and $\mathcal{J}$:

$$
\begin{array}{ll}
(i) & \Delta^{\mathcal{I}} = \Delta^{\mathcal{J}} \\
(ii) & a^{\mathcal{I}} = a^{\mathcal{J}} \text{ for all individuals } a \\
(iii) & p^{\mathcal{I}} = p^{\mathcal{J}} \text{ for all } p \in F \\
(iv) & p^{\mathcal{I}} \subseteq p^{\mathcal{J}} \text{ for all } p \in M \\
(v) & \text{there is } p \in M \text{ such that } p^{\mathcal{I}} \subset p^{\mathcal{J}}
\end{array}
$$

- A circumscriptive model of a KB is a model of KB which is minimal w.r.t $<_{CP}$ relation

Circumscription

Problems

- Extensions of minimized predicates may contain unknown individuals.
- Undecidable in the presence of non-empty Tbox and minimized properties [Bonatti, Lutz, Wolter: JAIR 2009].
- High Complexity for expressive DLs.

Grounded Circumscription

- Allow only named individuals in the extensions of minimized predicates.
- We say the pair (K,M) is a GC-KB K w.r.t the set of minimized predicates M in K.
- Preference relation for comparing two models

$\mathcal{I} \prec_M \mathcal{J}$, *iff all of the following hold:*

$$\begin{aligned}
&(i)\ \Delta^{\mathcal{I}} = \Delta^{\mathcal{J}} \text{ and } a^{\mathcal{I}} = a^{\mathcal{J}} \text{ for every } a \in \mathsf{N}_I \\
&(ii)\ W^{\mathcal{I}} \subseteq W^{\mathcal{J}} \text{ for every } W \in M \\
&(iii)\ \text{there exists a } W \in M \text{ such that } W^{\mathcal{I}} \subset W^{\mathcal{J}}
\end{aligned}$$

Grounded Circumscription

- A GC-model of (K,M):
  - Is a classical model of K,
  - Extensions of minimized predicates consist of only named individuals (and pairs), and
  - Is a minimal model with respect to the preference relation $\prec_M$

$\mathcal{I} \prec_M \mathcal{J}$, *iff all of the following hold:*

(i) $\Delta^{\mathcal{I}} = \Delta^{\mathcal{J}}$ *and* $a^{\mathcal{I}} = a^{\mathcal{J}}$ *for every* $a \in \mathsf{N}_I$
(ii) $W^{\mathcal{I}} \subseteq W^{\mathcal{J}}$ *for every* $W \in M$
(iii) *there exists a* $W \in M$ *such that* $W^{\mathcal{I}} \subset W^{\mathcal{J}}$

GC- Example

- I and J two models of KB (Assuming UNA)
- $hasAuthor^I = \{ (paper1^I, author1^I), (paper1^I, author2^I), (paper1^I, author3^I), (paper2^I, author3^I)\}$
- $hasAuthor^J = \{ (paper1^J, author1^J), (paper1^J, author2^J), (paper2^J, author3^J)\}$
- $hasAuthor^J \subset hasAuthor^I$
- $J \prec_M I$, I is not a GC-Model of (K,M)

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Contribution

- Grounded circumscription semantics – An intuitive approach to Local Closed World Assumption.
- Decidable even with minimized/closed roles.
- A Tableau procedure to reason with GC knowledge bases.

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Decidability (Sketch)

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- Underlying DL is decidable
- Finite number of named individuals
- A GC-model can be constructed by
  - Assigning a minimal set of named individuals to each minimized classes.
  - A minimal set of pairs of named individuals to minimized Roles .
- Since we have a finite set to choose from the problem of finding a GC-model is decidable.

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Algorithm (GC-satisfiability)

- GC-satisfiability : A tableau procedure for testing GC-KB (K,M) satisfiability
- Task – To check if GC-KB (K,M) has a GC-model.
- Reduced to checking for grounded model (not necessarily minimal).
- Modify exiting Tableau and add expansion rules to ground minimized predicates.

Key

- It suffices to show that there is a grounded model to check GC-satisfiability.
- Grounded Model: A model of GC-KB (K,M) such that, the extensions of the minimized predicates contain only named individuals.
- GC-model: A grounded model which is also a minimal model of the GC-KB (K,M)

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New Expansion Rules

- Grounding closed predicates.
- Rule for $C \in M$: If a variable node x, with $C \in L(x)$ then choose a nominal node and merge the labels (grounding), disregard node x.
- Rule for $R \in M$: If $R \in L(x,y)$ and at least one of x, y is a variable, then ground the variable nodes by choosing a nominal node.
- NOTE: These rules are not applied to blocked nodes in the graph.

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New Tableau Rules

$\longrightarrow_{GC_C}$:	if $C \in \mathcal{L}(x), C \in M, x \notin \mathsf{Ind}(K)$ and x is not blocked **then** for some $a \in \mathsf{Ind}(K)$ do 1. $\mathcal{L}(a) := \mathcal{L}(a) \cup \mathcal{L}(x)$, 2. if x has a predecessor y, then $\mathcal{L}(y,a) := \mathcal{L}(y,a) \cup \mathcal{L}(y,x)$, 3. remove x and all incoming edges to x in the completion graph
$\longrightarrow_{GC_R}$:	if $R \in \mathcal{L}(x,y), R \in M$ and y is not blocked. **then** initialize variables $x' := x$ and $y' := y$, and do 1. if $x \notin \mathsf{Ind}(K)$ then for some $a \in \mathsf{Ind}(K), \mathcal{L}(a) := \mathcal{L}(a) \cup \mathcal{L}(x)$, $x' := a$. 2. if $y \notin \mathsf{Ind}(K)$ for some $b \in \mathsf{Ind}(K), \mathcal{L}(b) := \mathcal{L}(b) \cup \mathcal{L}(y)$ and $y' := b$ 3. if $x' = a$ and x has a predecessor z, then $\mathcal{L}(z,a) := \mathcal{L}(z,a) \cup \mathcal{L}(z,x)$. 4. $\mathcal{L}(x',y') := \mathcal{L}(x',y') \cup \{R\}$ 5. if $x' = a$ remove x and all incoming edges to x and if $y' = b$ remove y and all incoming edges to y from the completion graph.

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GC-Satisfiability

- Start with initial graph (Abox).
- Apply expansion rules exhaustively.
- If there is a inconsistency free completion graph, then GC-KB is GC-satisfiable.
- Blocking
- Termination.
- Sound and complete.

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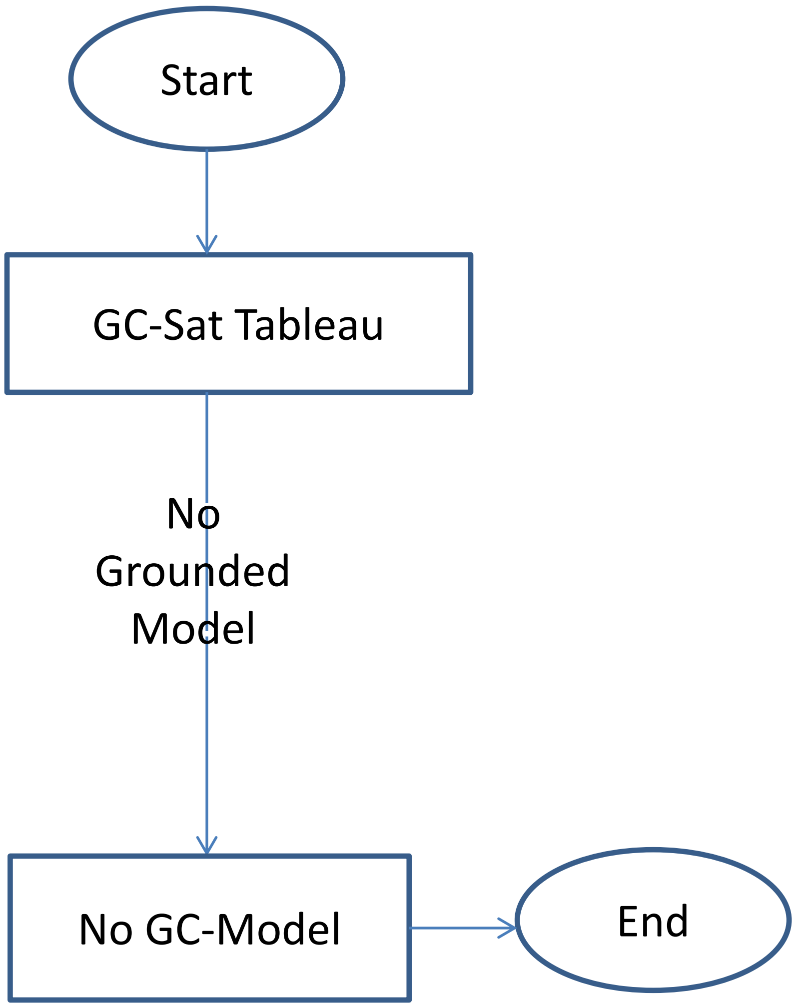
Beyond Satisfiability

- Instance checking, concept satisfiability, and concept subsumption.
- Reducing other inference problems to GC-satisfiability is not straight forward.
- GC-satisfiability just looks for grounded models.
- Tableau2: Try to find a smaller model.

Tableau2

- Initialization: Abox and Nodes from a consistent completion graph from GC-sat checker.
- Expansion rules same as GC-sat but $\exists R.C$ rule does not add new nodes.
- Preference clash - if a completion graph represents a bigger model than initial model .

Finding GC-model



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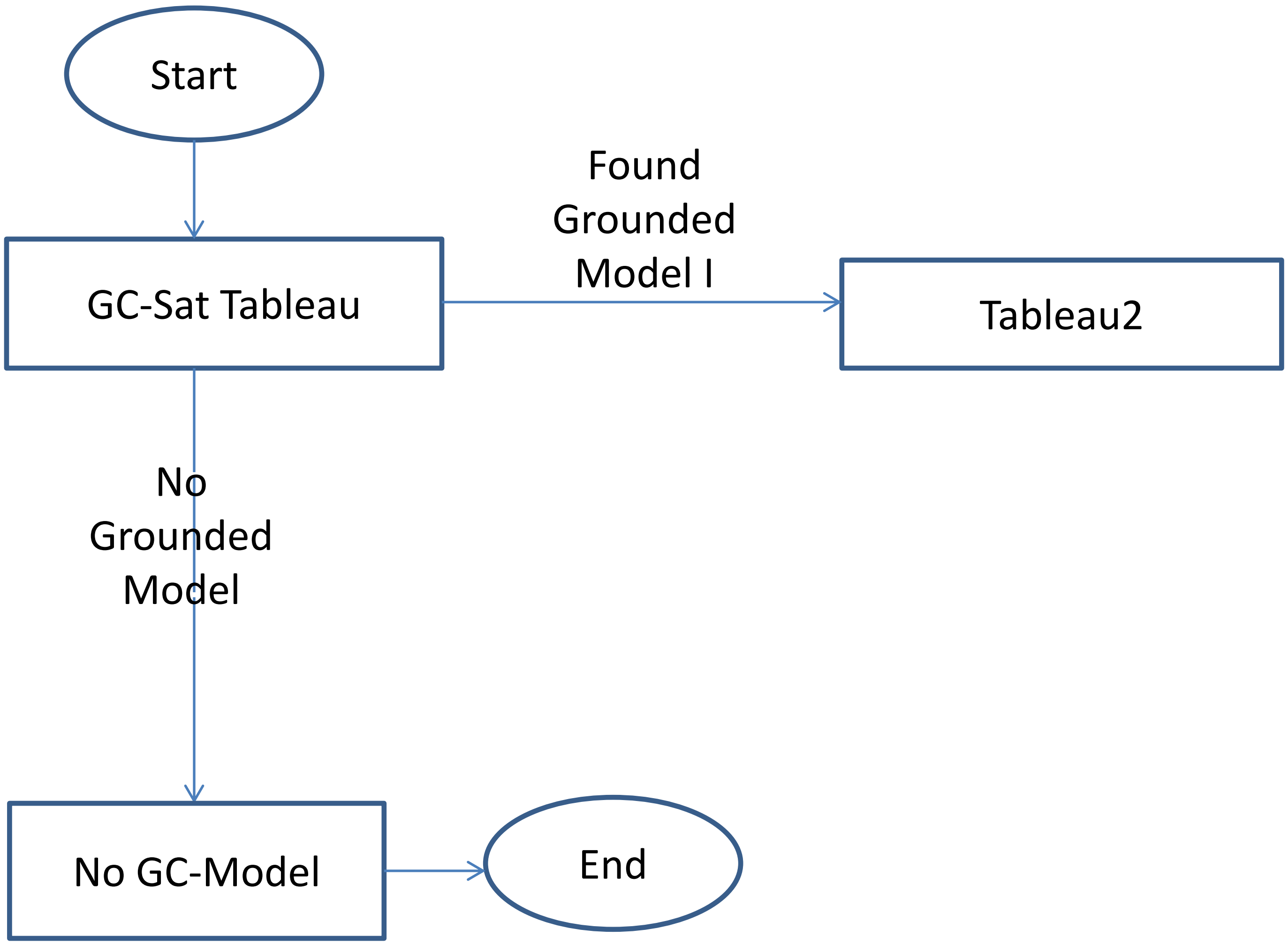

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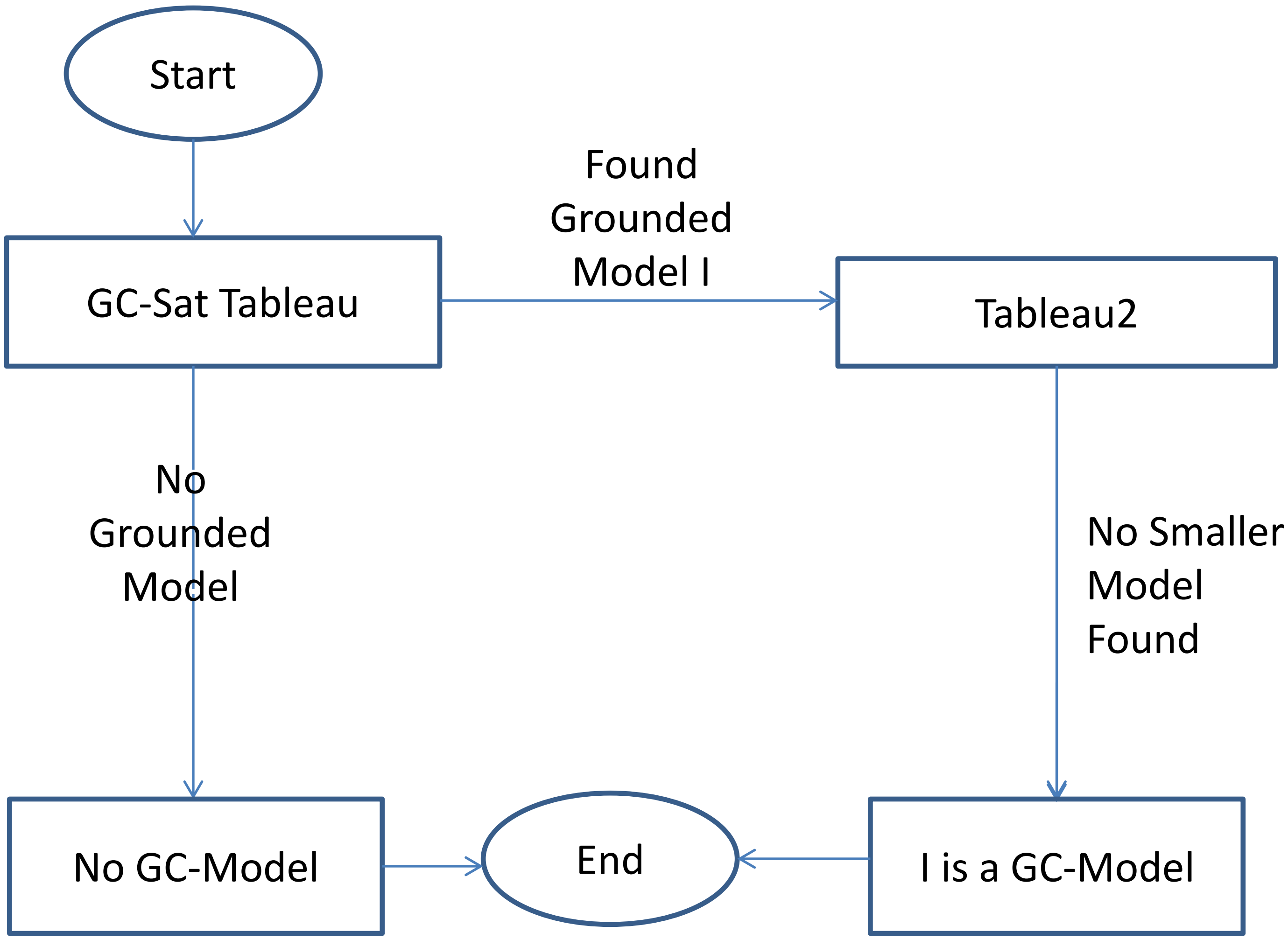

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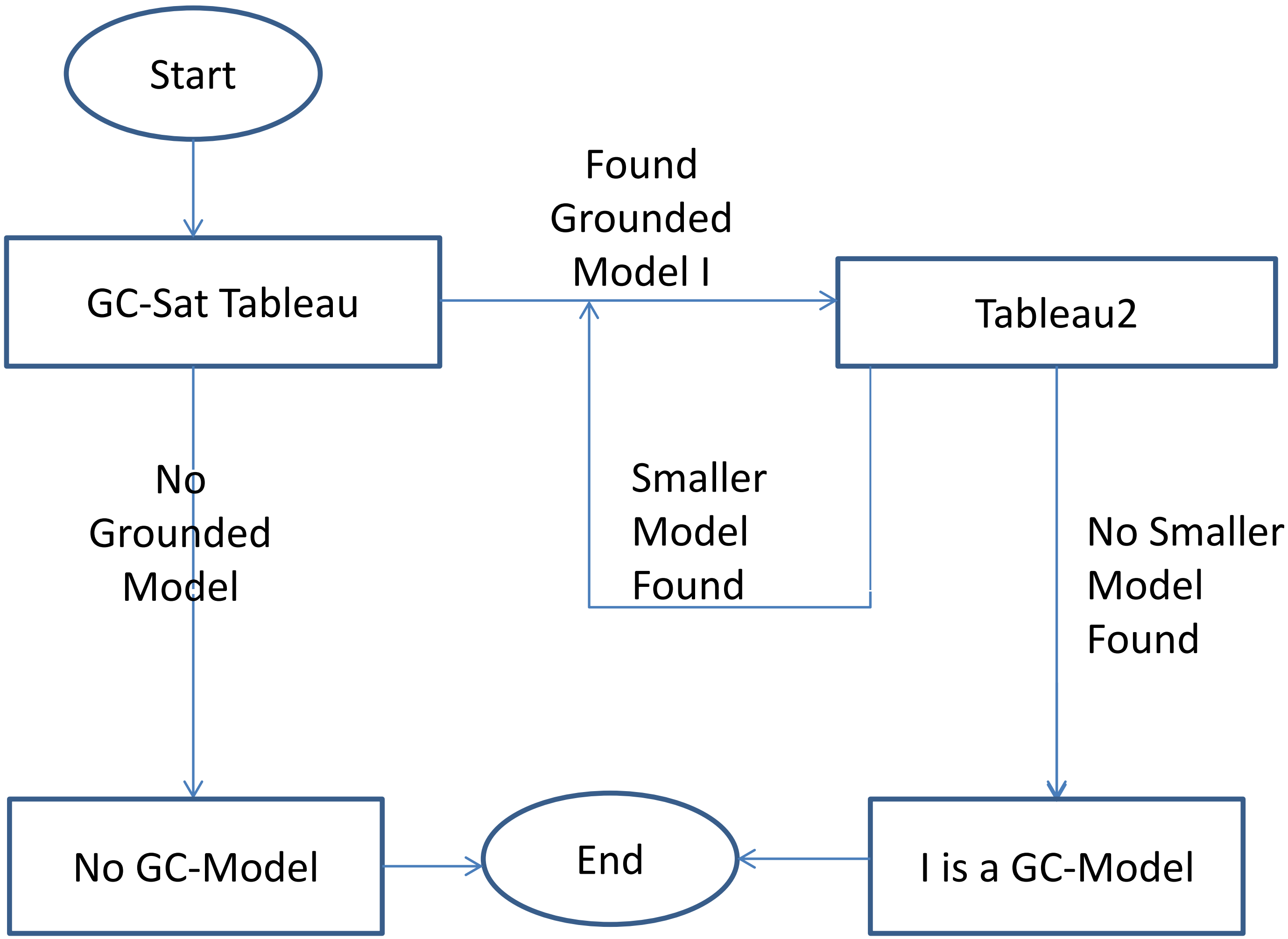

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Inference Problems

- Instance Checking C(a): Invoke the GC-Model Finder algorithm and verify if $C \in L(a)$ for all GC-Models.
- Concept satisfiability: Invoke the GC-Model Finder algorithm and verify if $C \in L(a)$ for at least one named individual in all GC-Models.
- Subsumption: Reducible to Concept satisfiability.

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Conclusion and Outlook

- Conclusion
  - A new approach to LCWA, Grounded circumscription.
  - Decidable
  - Reducing one reasoning task to other is not trivial.
  - Algorithm for reasoning with GC.
- Future work:
  - Find smarter reasoning algorithms.
  - Complexity analysis for all OWL fragments.
  - Implementation for use in real world.

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Thanks!