Description Logic Reasoning

Basic Inference Problems

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- KB consistency **reducible** to concept consistency via **internalisation**
  - For logics supporting, e.g., a transitive "top" role

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- Return "C is consistent" **iff** C is consistent
  - Tree model property

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- $\mathbf{T}$ **fully expanded** if no rules are applicable
- C satisfiable iff fully expanded clash free $\mathbf{T}$ found
  - Trivial correspondence between such a $\mathbf{T}$ and a model of C

Tableaux Rules for $\mathcal{ALC}$

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$x \bullet \{C_1 \sqcap C_2, \ldots\}$	$\rightarrow_\sqcap$	$x \bullet \{C_1 \sqcap C_2, C_1, C_2, \ldots\}$
$x \bullet \{C_1 \sqcup C_2, \ldots\}$	$\rightarrow_\sqcup$	$x \bullet \{C_1 \sqcup C_2, C, \ldots\}$ for $C \in \{C_1, C_2\}$
$x \bullet \{\exists R.C, \ldots\}$	$\rightarrow_\exists$	$x \bullet \{\exists R.C, \ldots\}$ $R \downarrow$ $y \bullet \{C\}$
$x \bullet \{\forall R.C, \ldots\}$ $R \downarrow$ $y \bullet \{\ldots\}$	$\rightarrow_\forall$	$x \bullet \{\forall R.C, \ldots\}$ $R \downarrow$ $y \bullet \{C, \ldots\}$

Tableaux Rule for Transitive Roles

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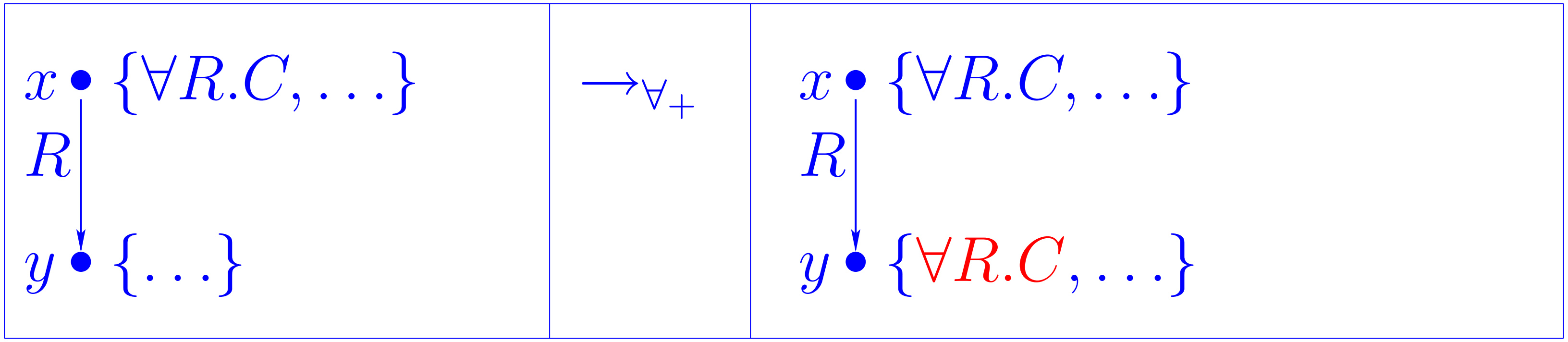

Where R is a transitive role (i.e., $(R^{\mathcal{I}})^{+} = R^{\mathcal{I}}$)

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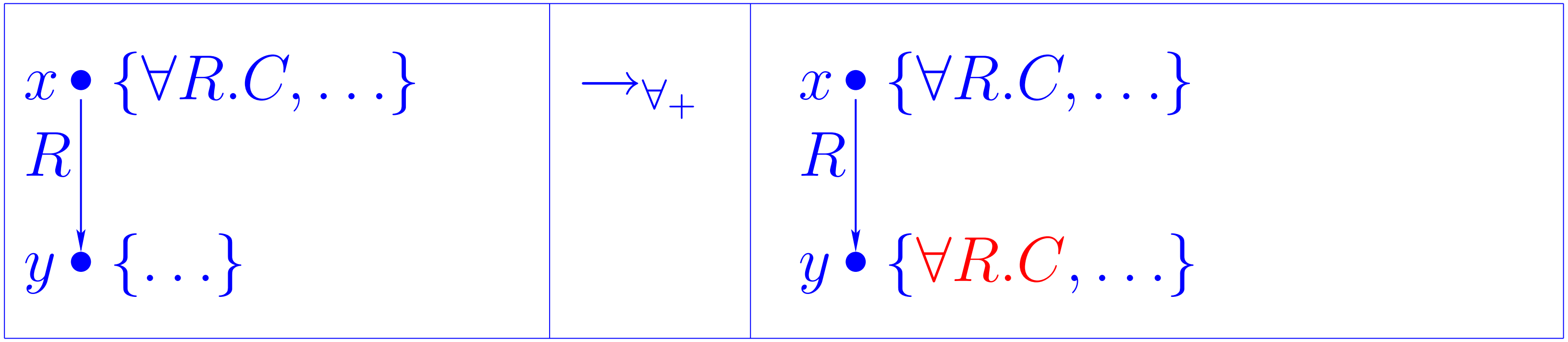

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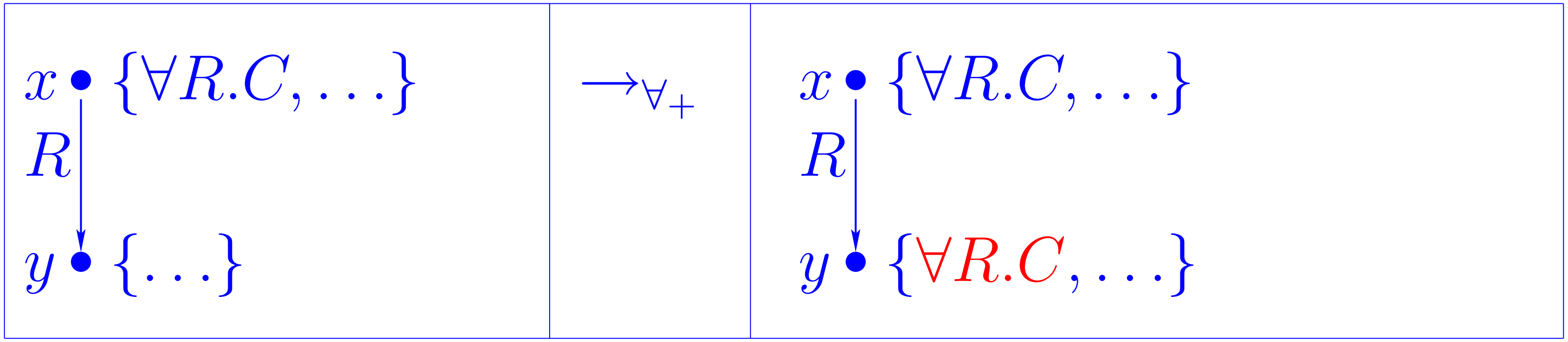

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- ☞ No longer naturally terminating (e.g., if $C = \exists R.\top$)
- ☞ Need blocking
  - Simple blocking suffices for $\mathcal{ALC}$ plus transitive roles
  - I.e., do not expand node label if ancestor has superset label
  - More expressive logics (e.g., with inverse roles) need more sophisticated blocking strategies

Tableaux Algorithm — Example

Test satisfiability of $\exists S.C \sqcap \forall S.(\neg C \sqcup \neg D) \sqcap \exists R.C \sqcap \forall R.(\exists R.C)\}$ where R is a **transitive** role

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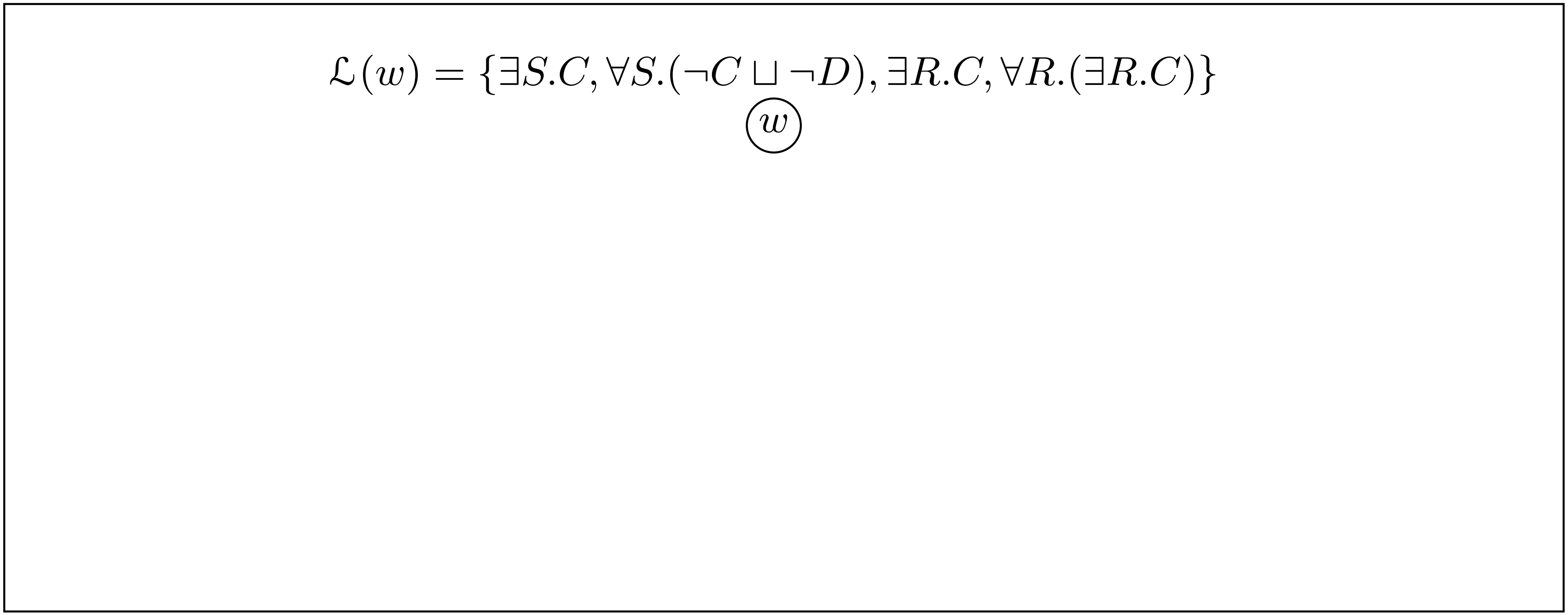

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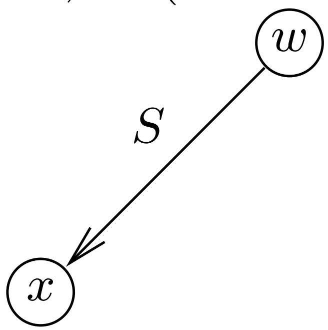

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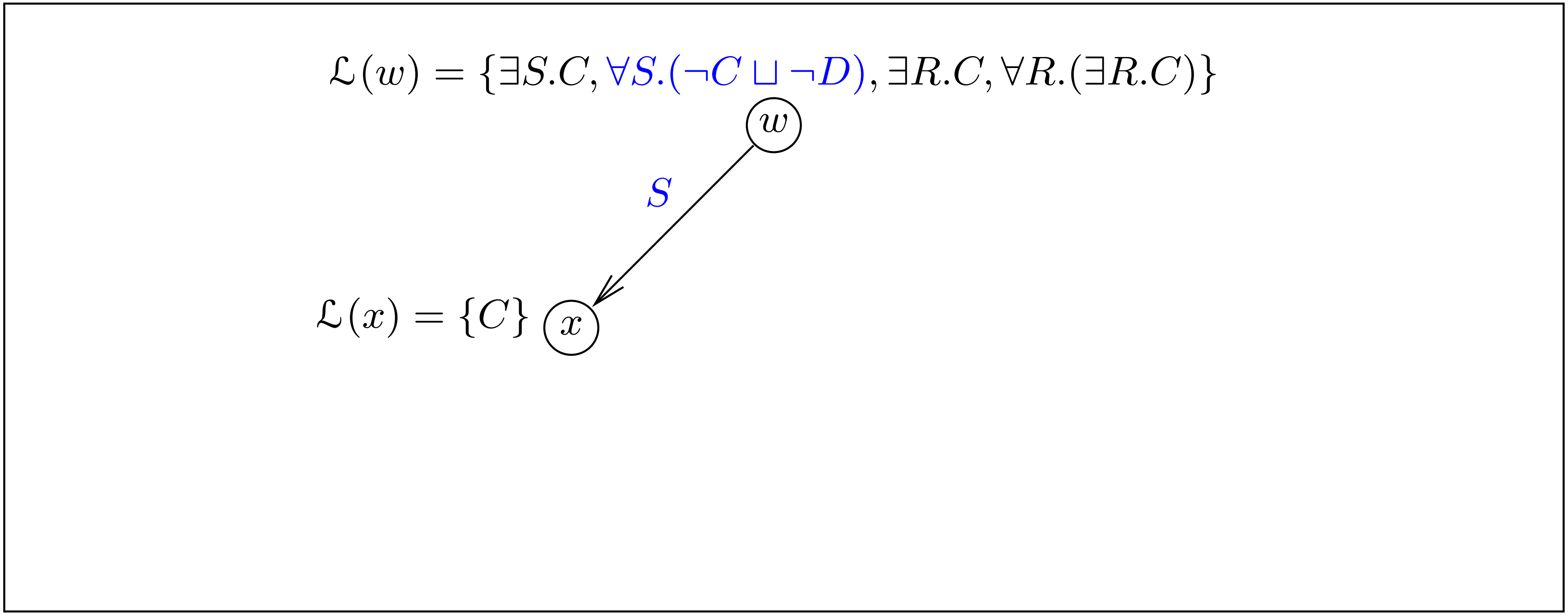

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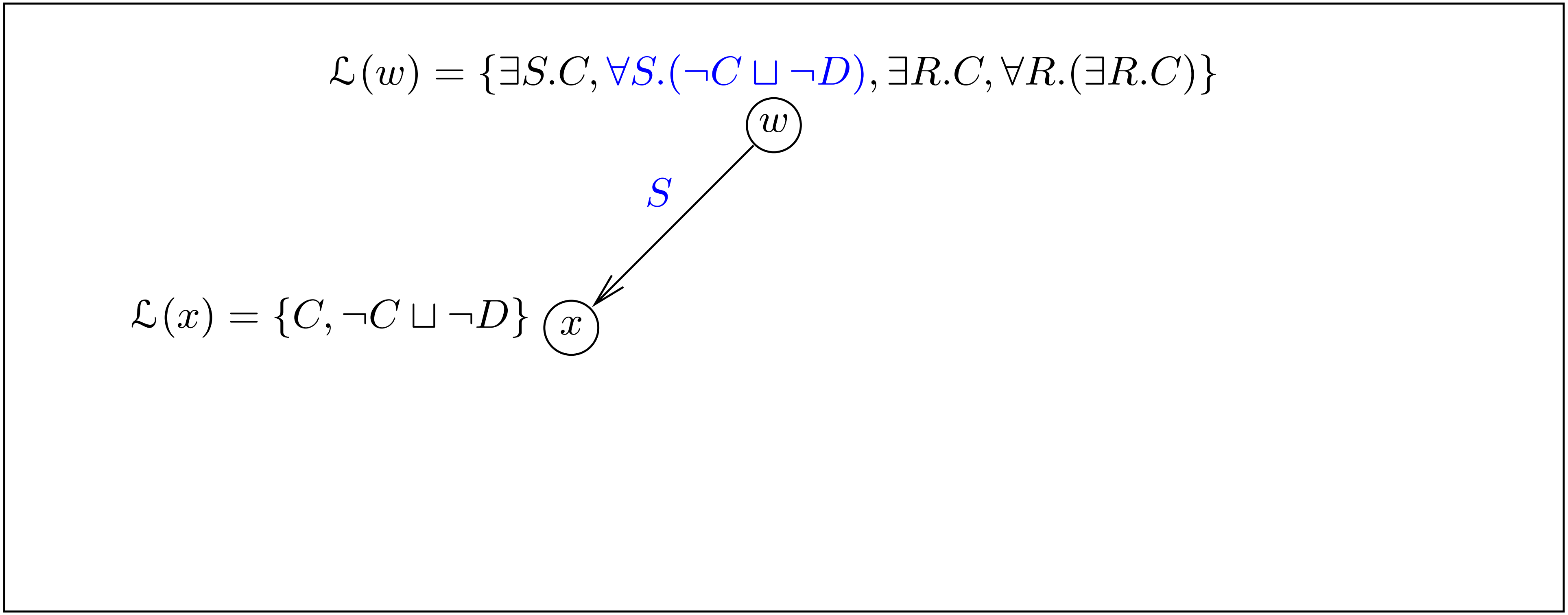

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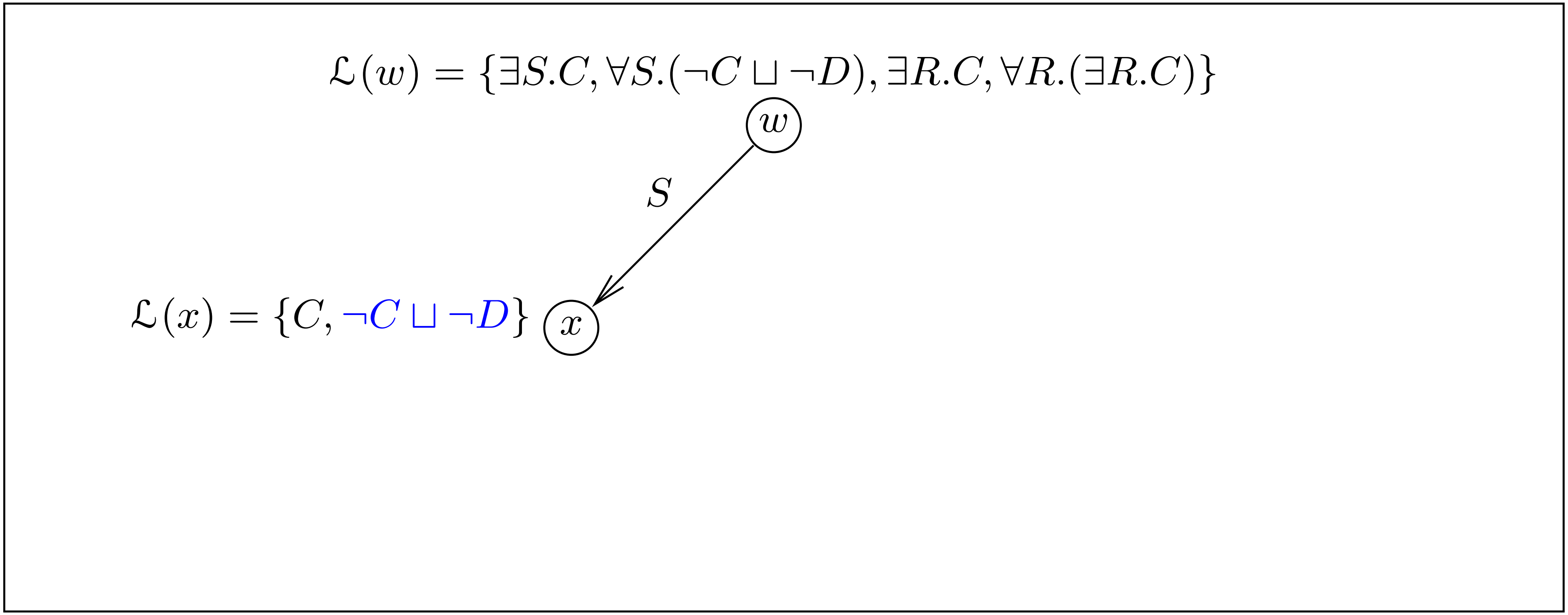

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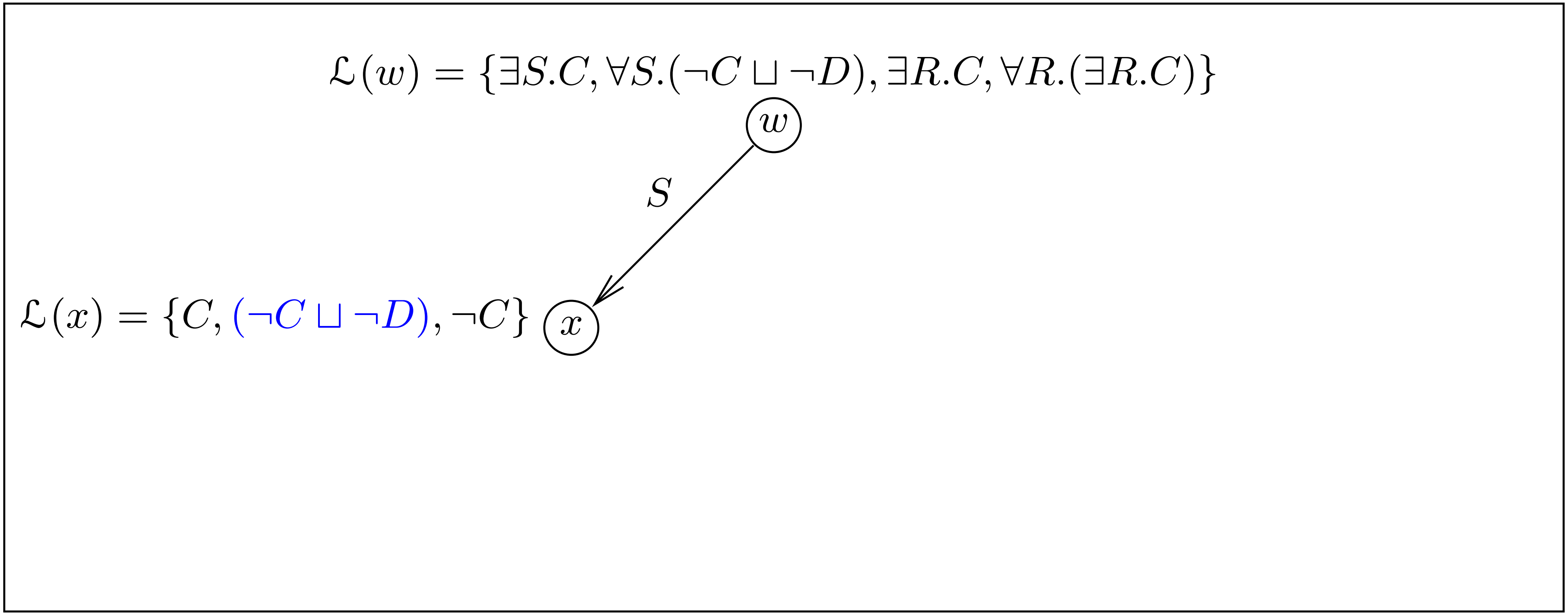

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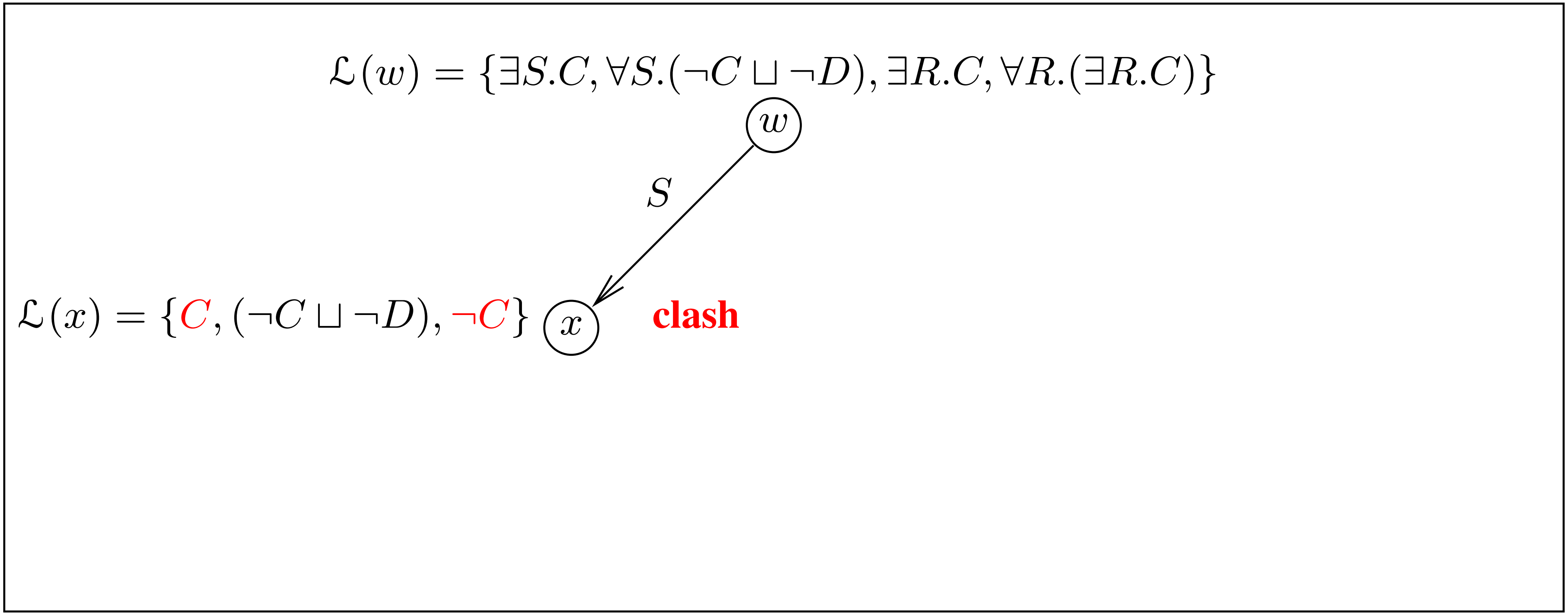

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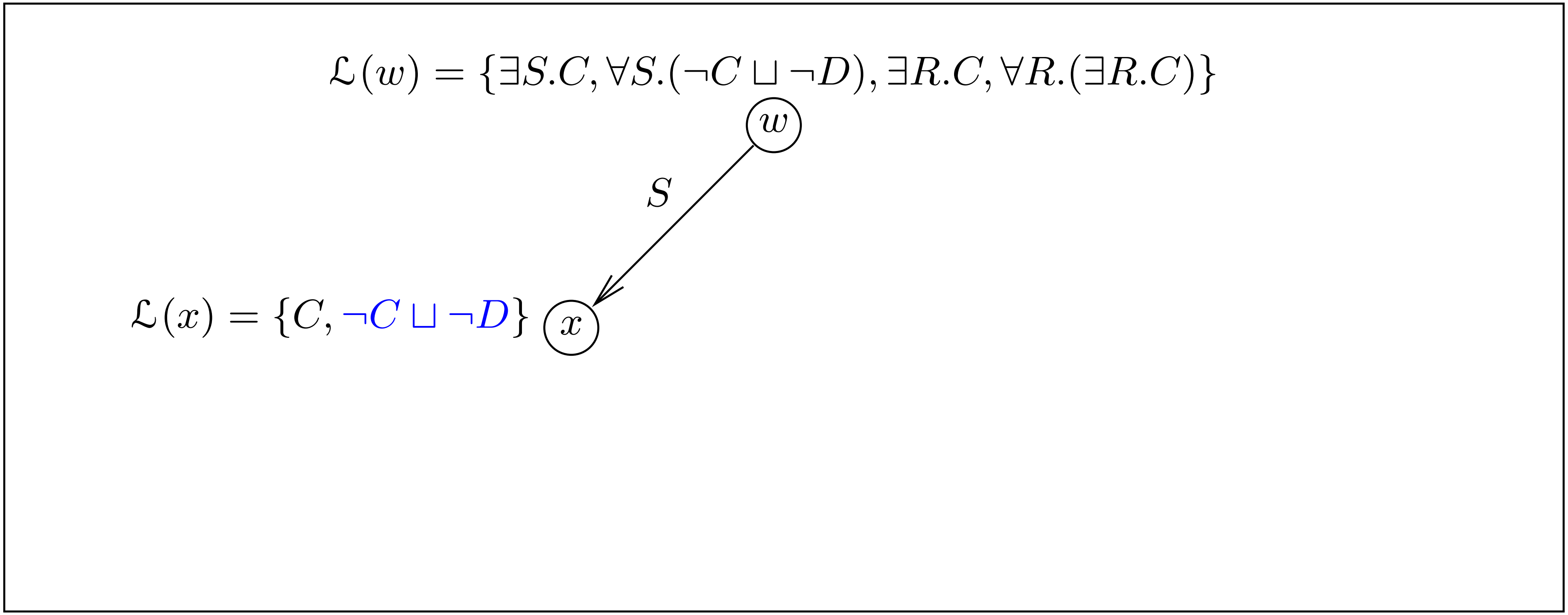

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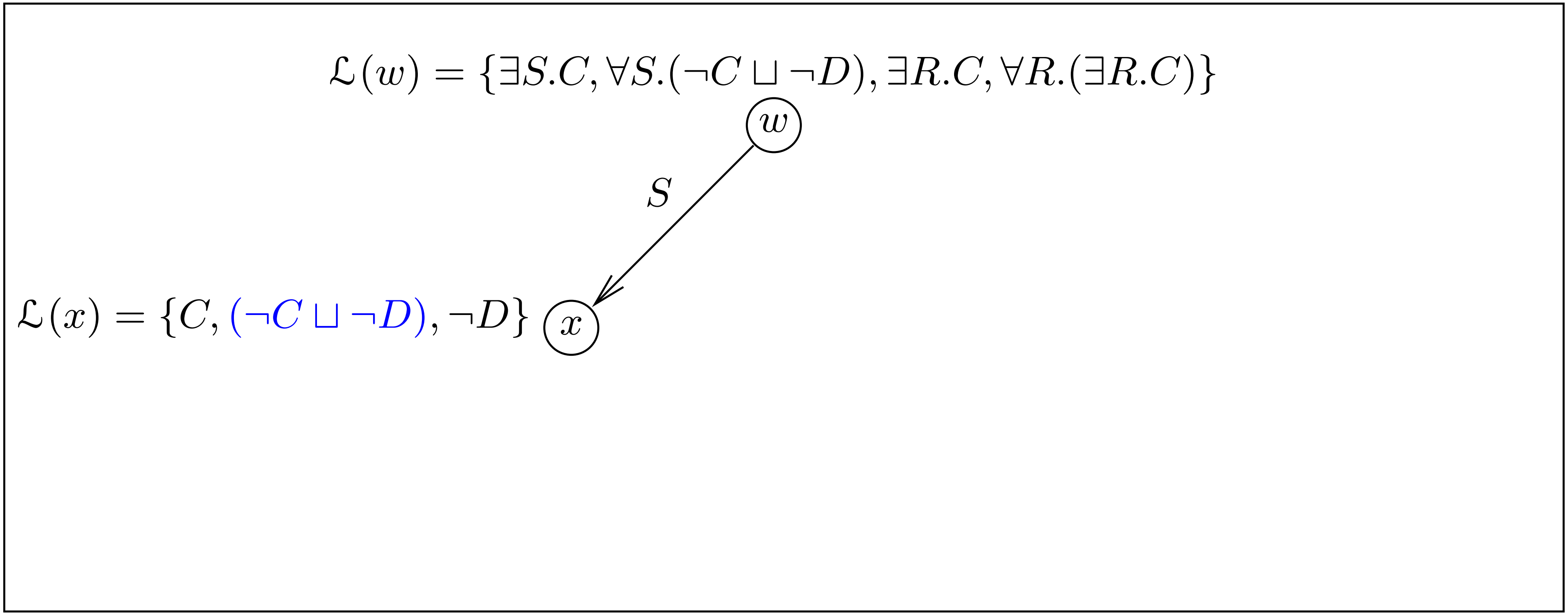

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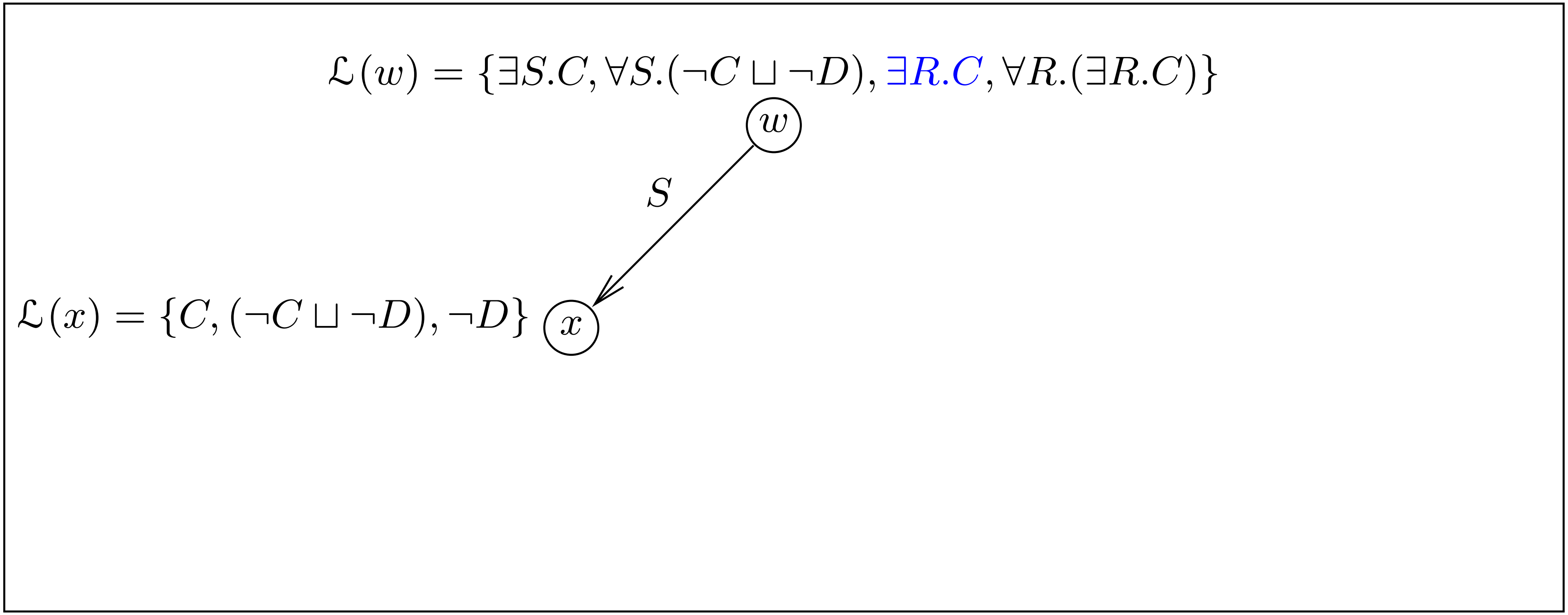

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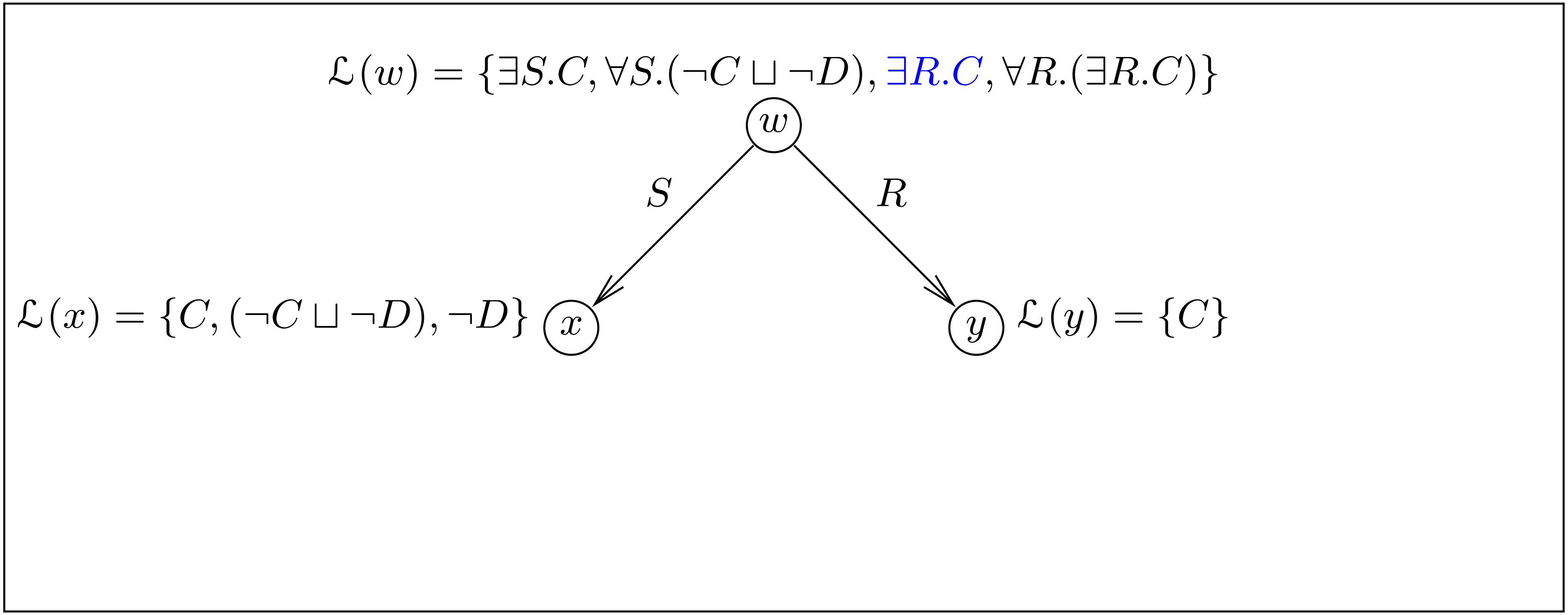

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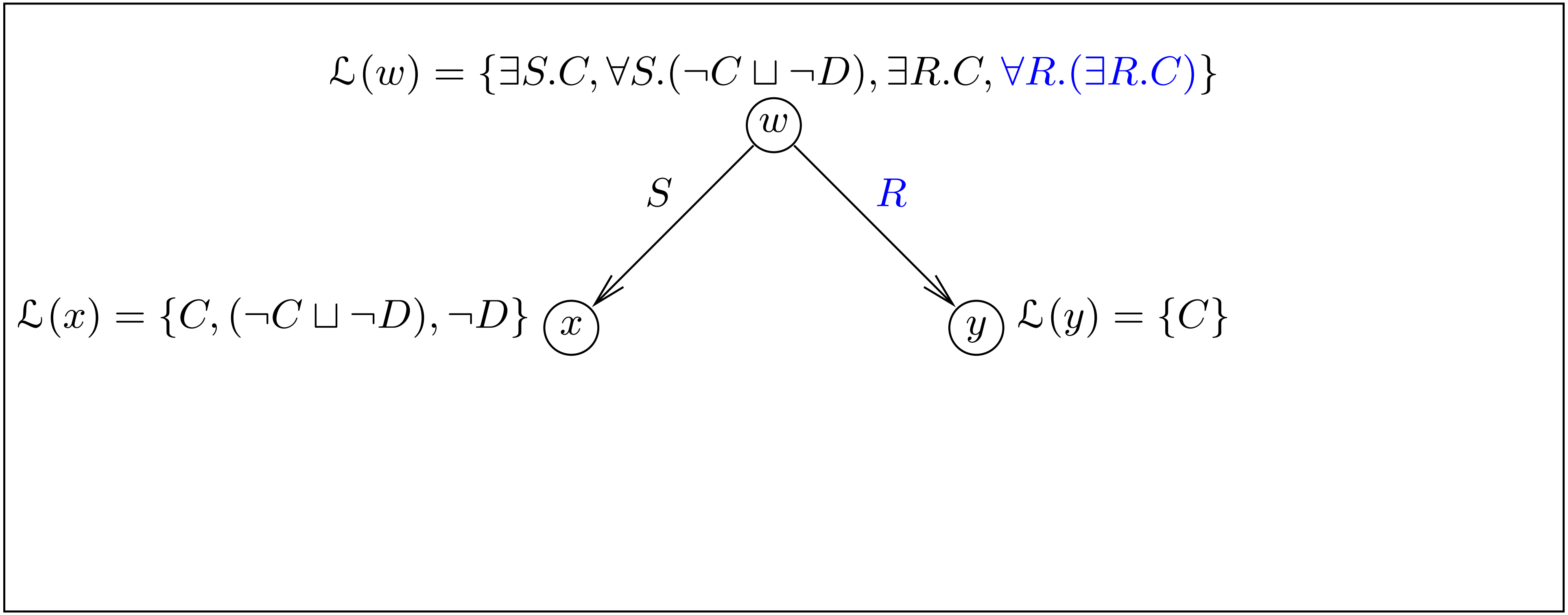

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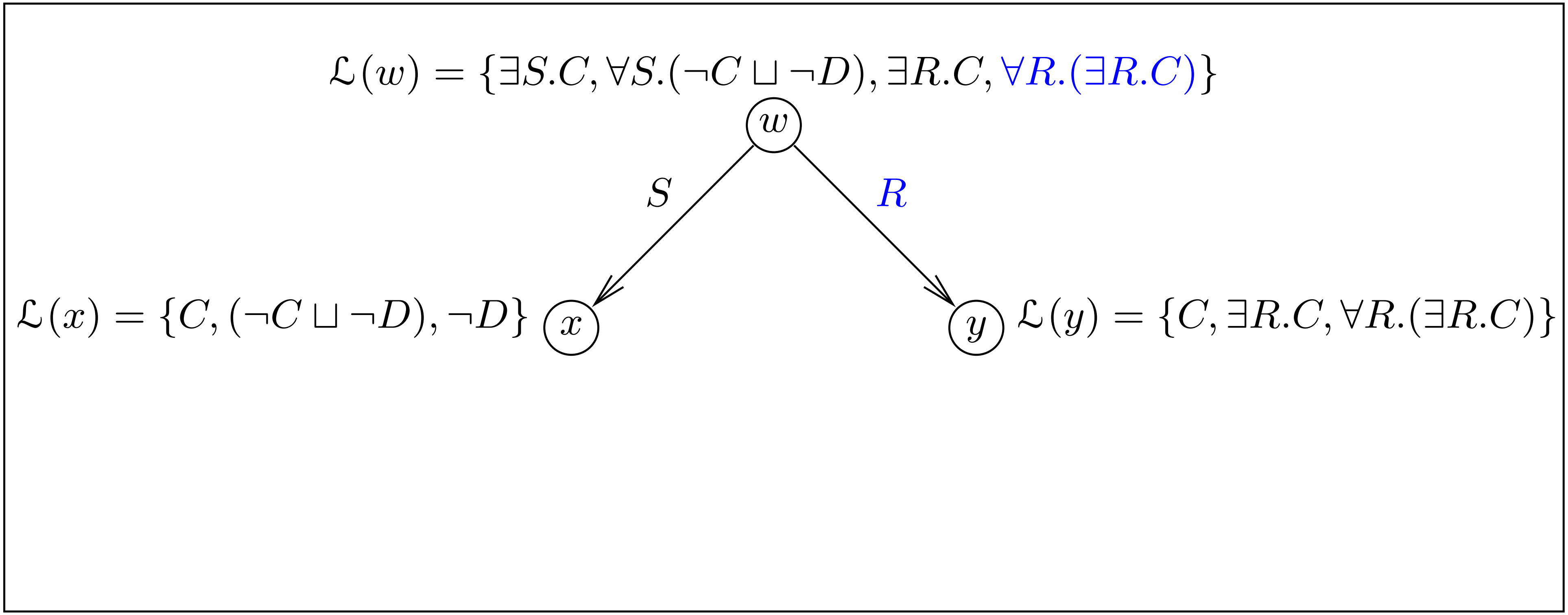

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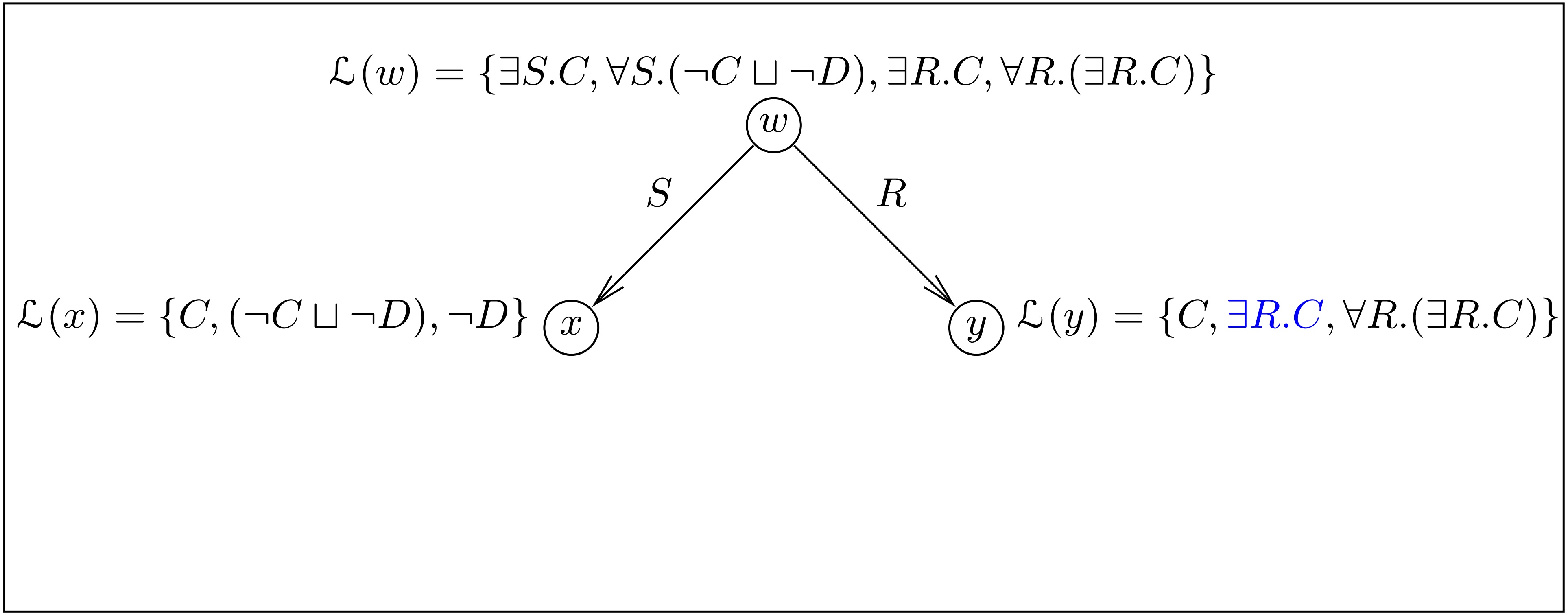

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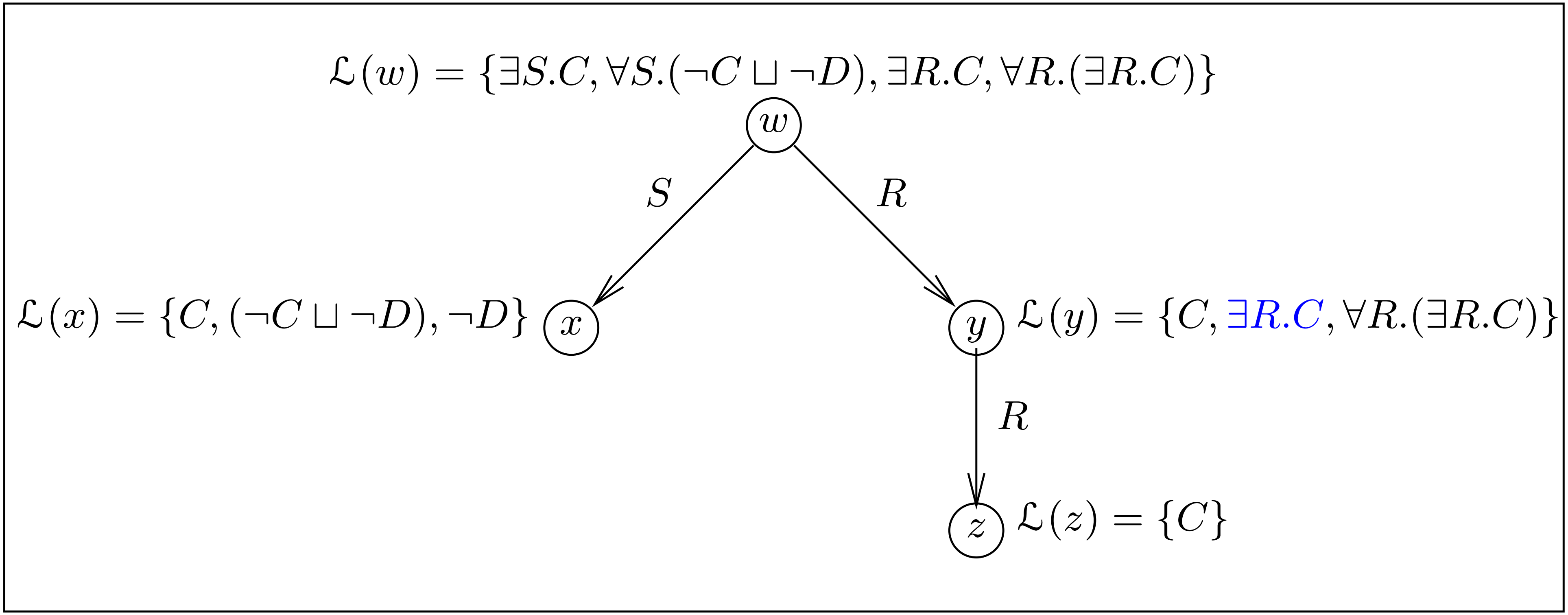

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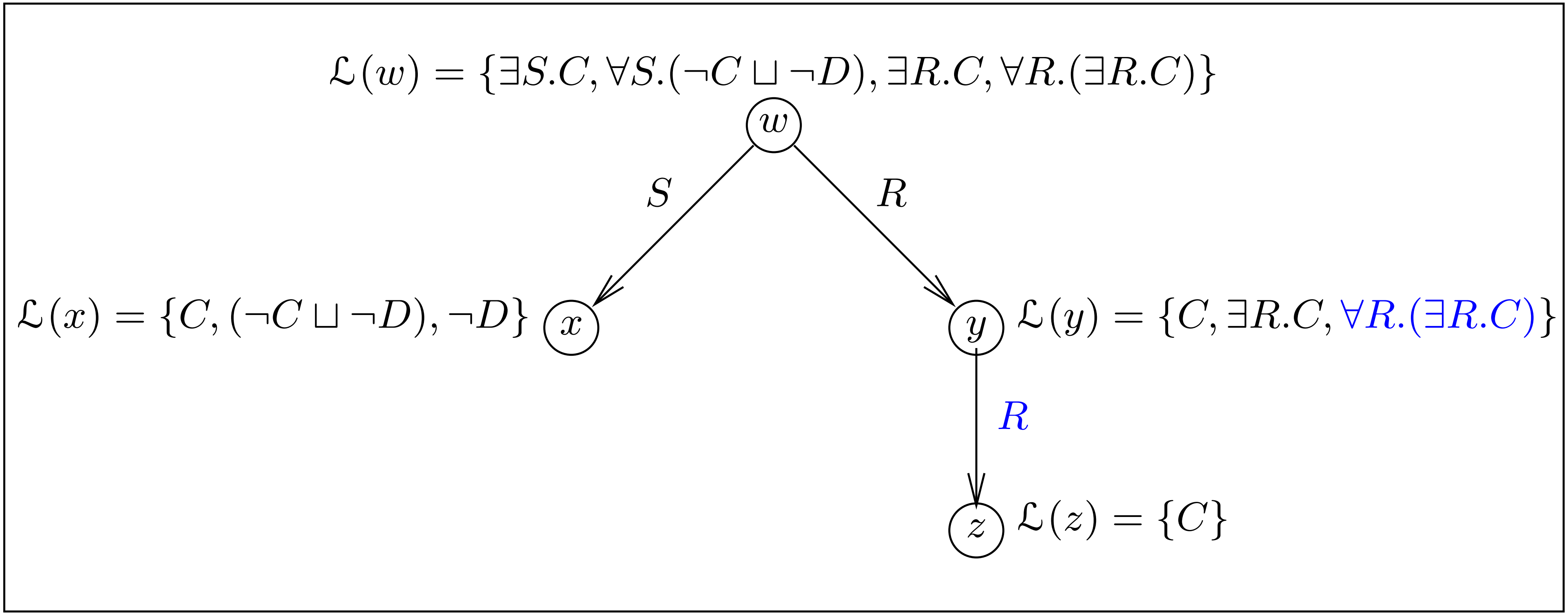

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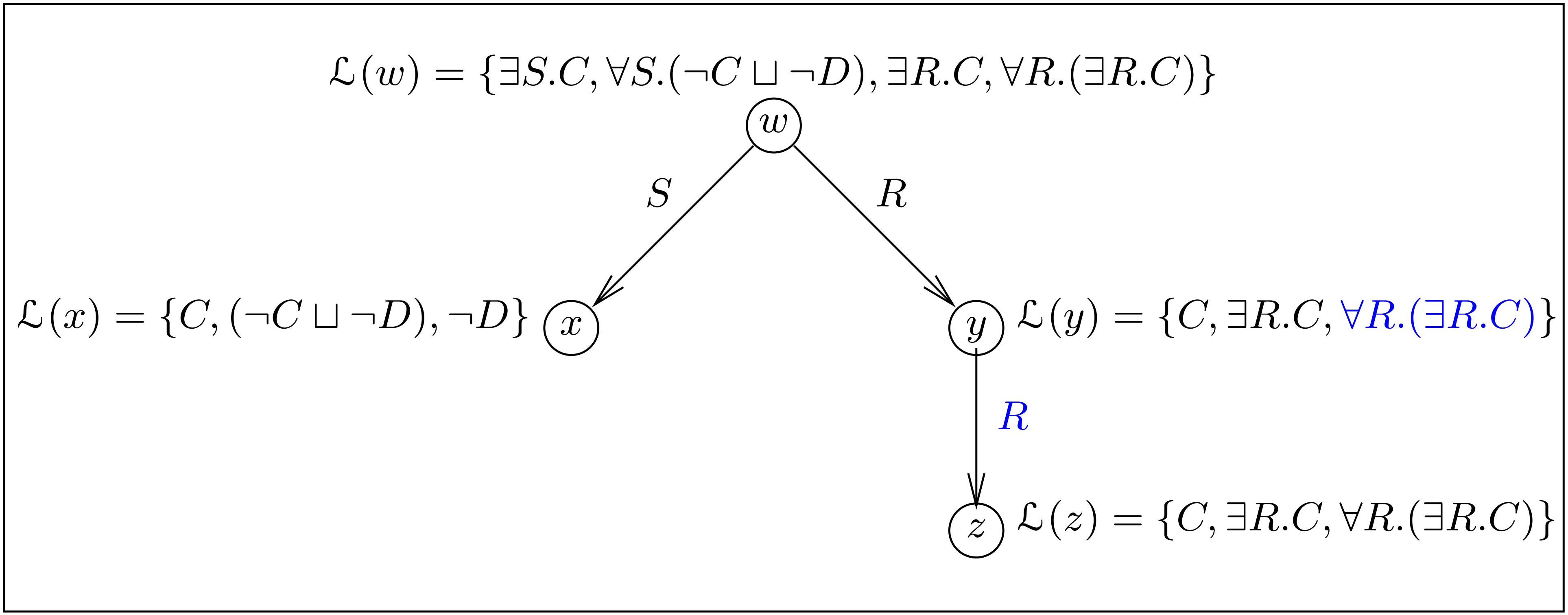

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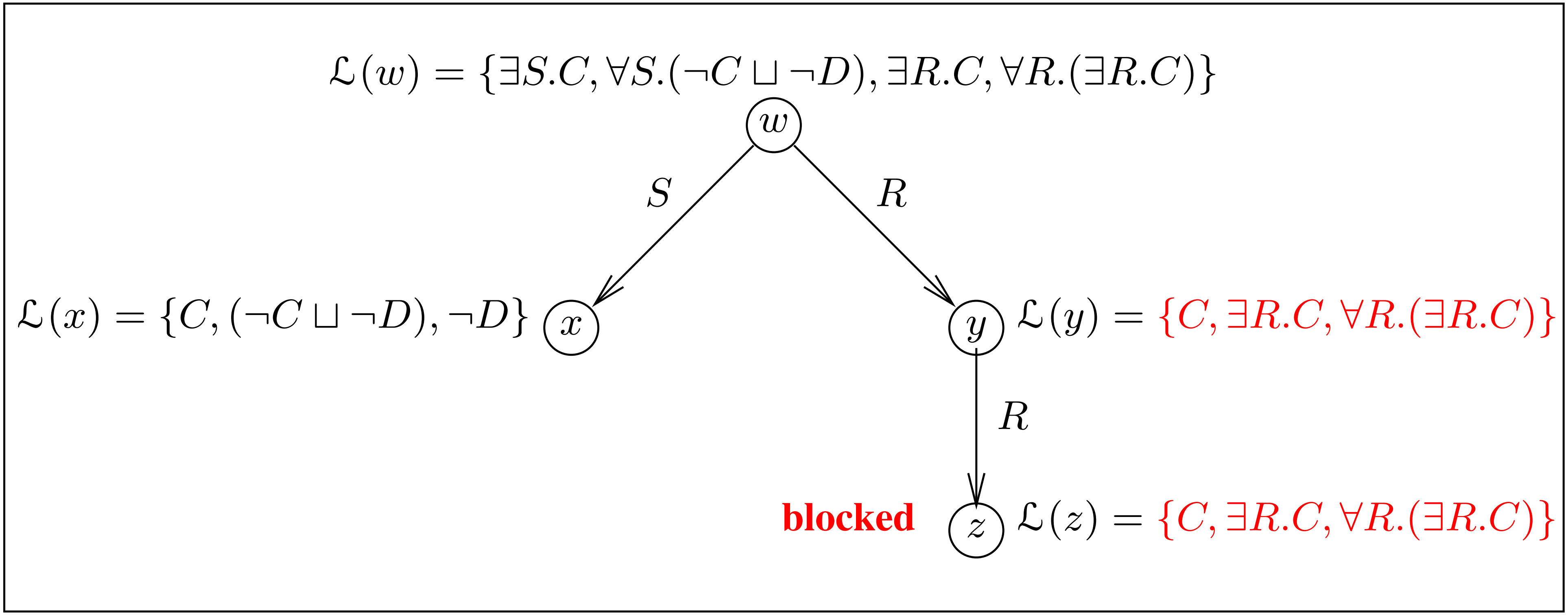

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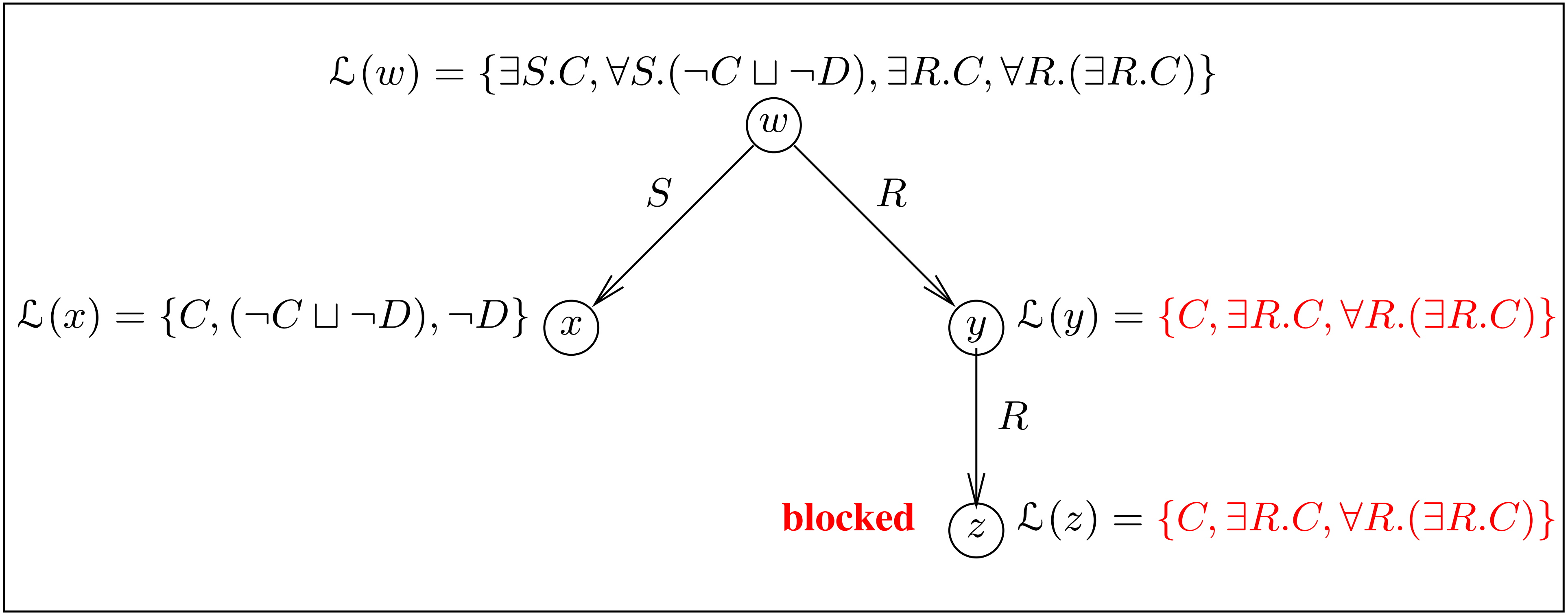

Concept is **satisfiable**: $\mathbf{T}$ corresponds to **model**

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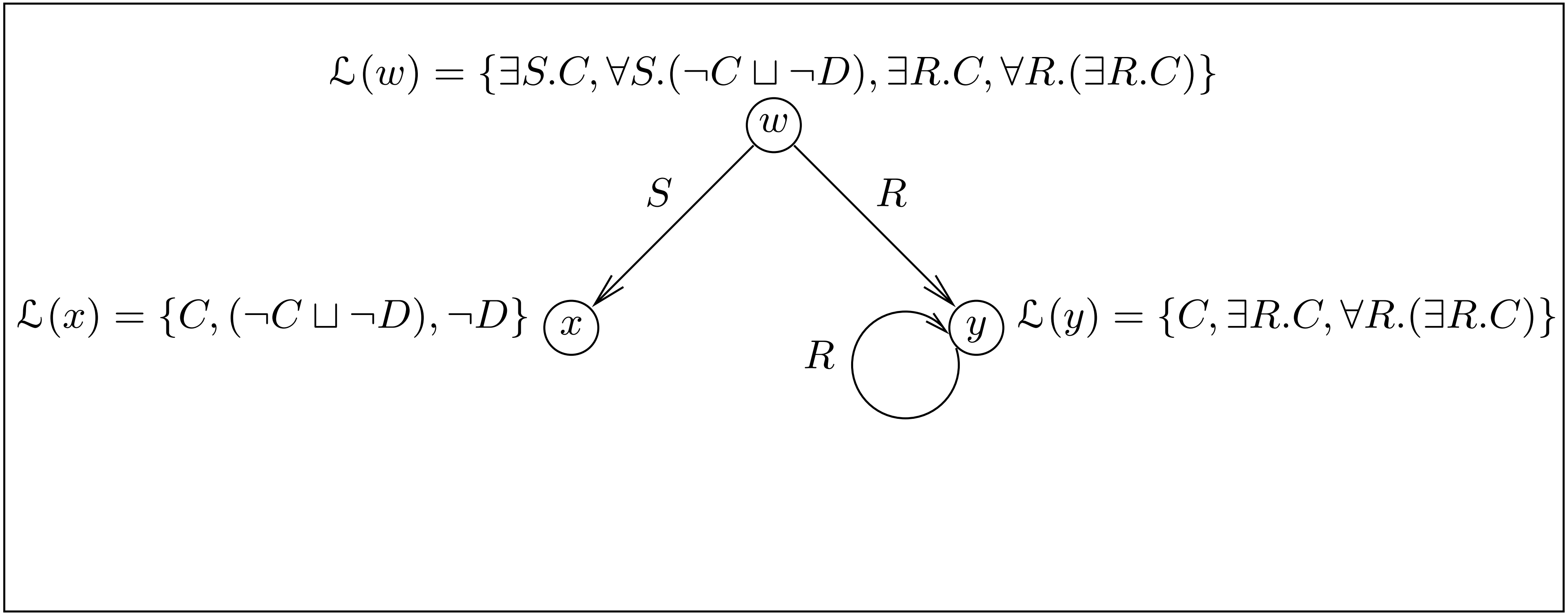

Concept is **satisfiable**: $\mathbf{T}$ corresponds to **model**

More Advanced Techniques

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Satisfiability w.r.t. a Terminology

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- Number restrictions
- Inverse roles
- Concrete domains and datatypes
- Aboxes
- etc.

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- ☞ Extend **expansion rules** and use more sophisticated **blocking** strategy
- ☞ **Forest** instead of Tree (for Aboxes)
  - Root nodes correspond to individuals in Abox

Implementing DL Systems

Naive Implementations

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  - Mitigated by:
    - Careful **choice of algorithm**
    - Highly **optimised implementation**

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  - **BUT** even simple domain encoding is **disastrous** with large numbers of roles

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- ☞ Optimised **subsumption** testing (search for models)
  - Normalisation and simplification of concepts
  - Absorption (rewriting) of general axioms
  - Davis-Putnam style semantic branching search
  - Dependency directed backtracking
  - Caching of satisfiability results and (partial) models
  - Heuristic ordering of propositional and modal expansion
  - ...

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- **Highly effective** — essential for usable system
  - E.g., GALEN KB, 30s (with) $\longrightarrow$ months++ (without)

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E.g., if $\{\exists R.\neg A \sqcap \forall R.(A \sqcap B) \sqcap (C_1 \sqcup D_1) \sqcap \ldots \sqcap (C_n \sqcup D_n)\} \subseteq \mathcal{L}(x)$

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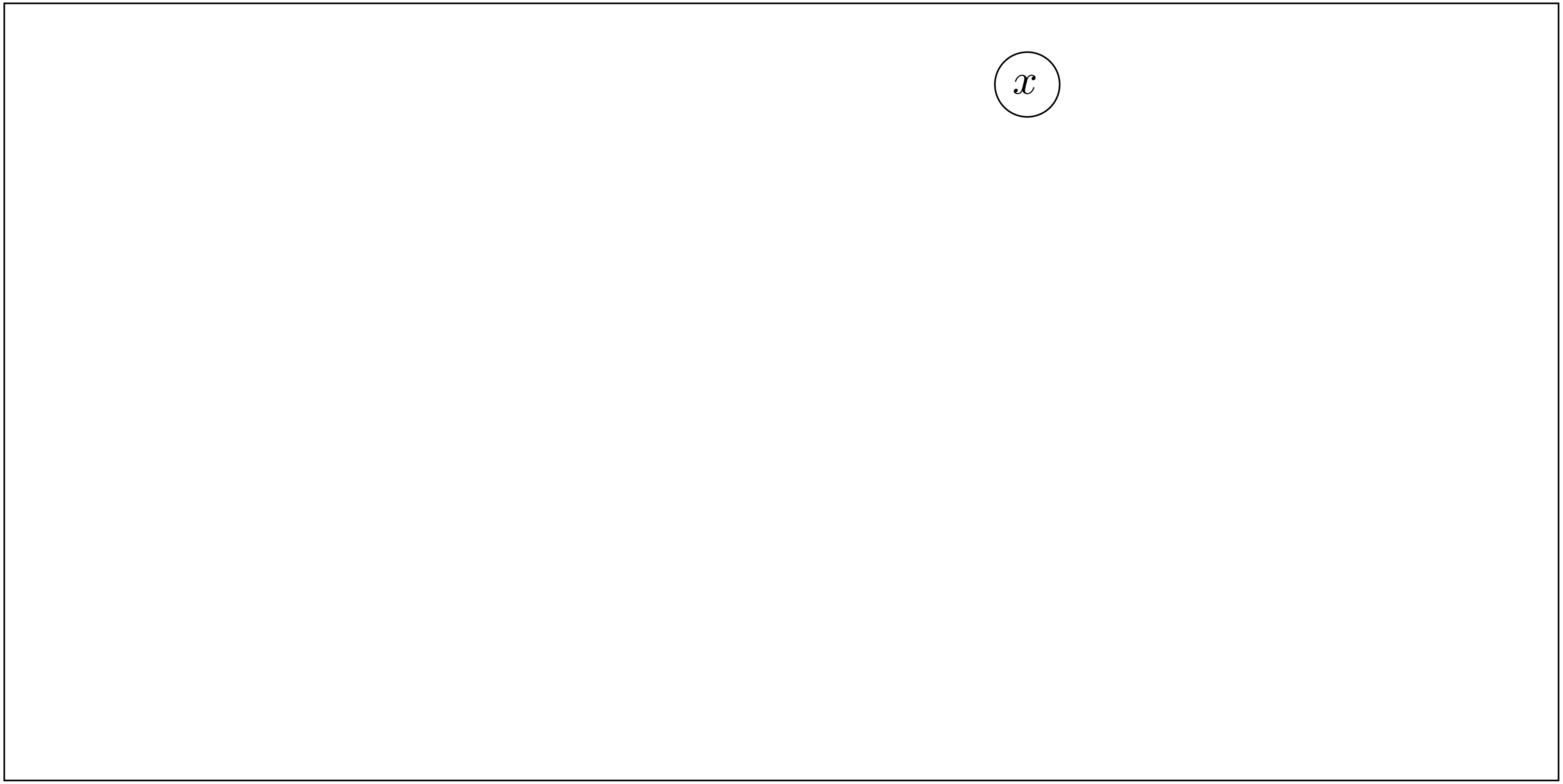

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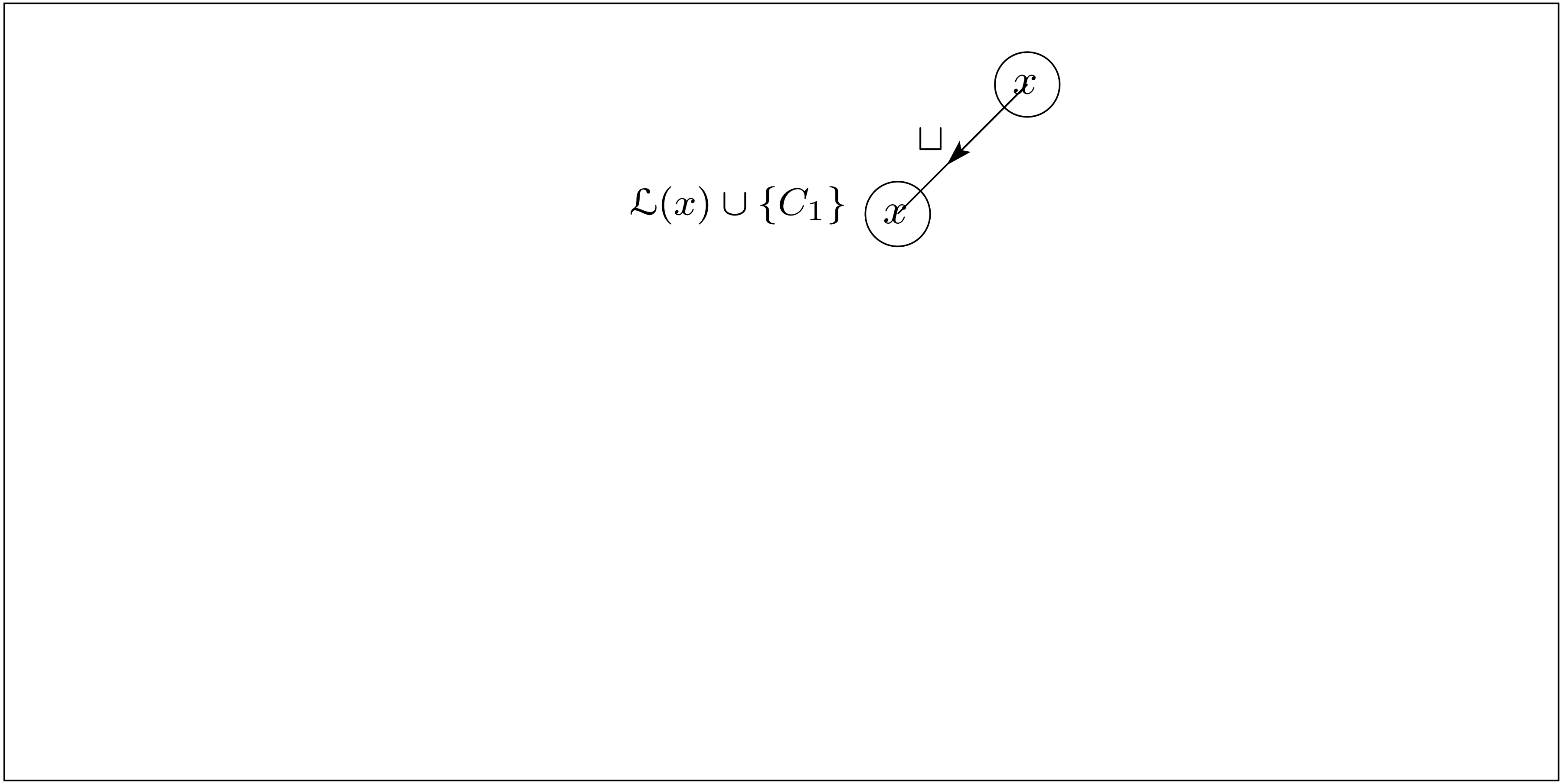

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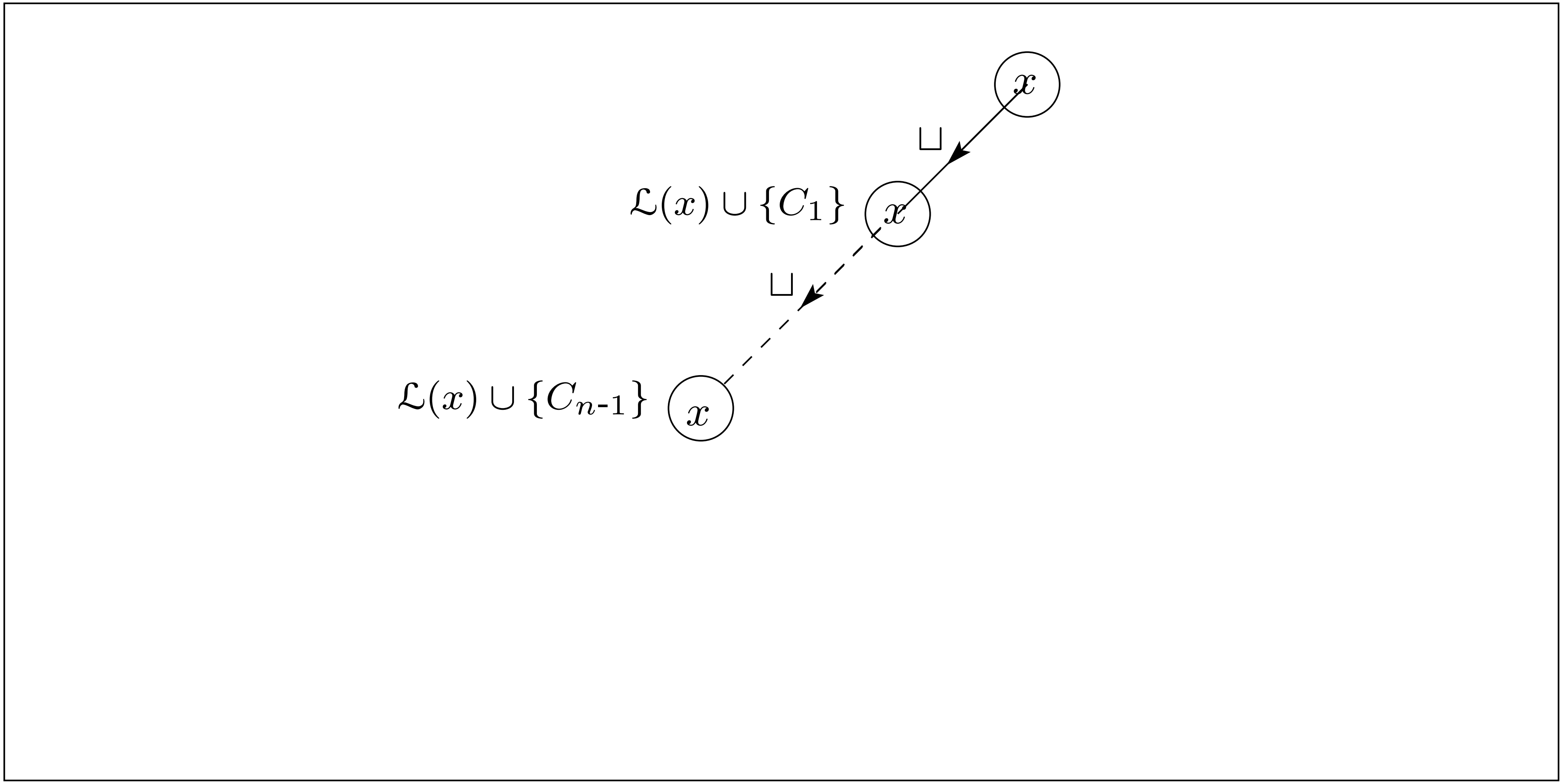

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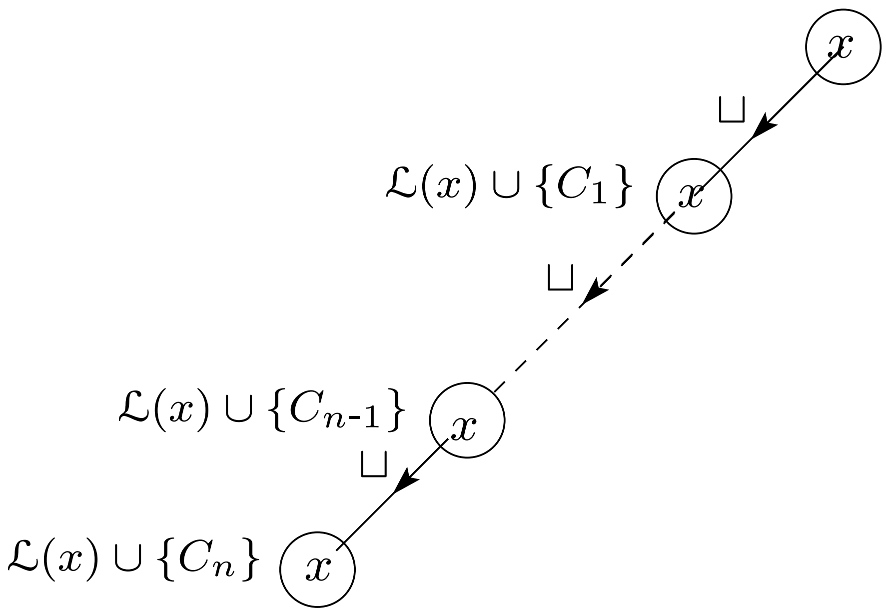

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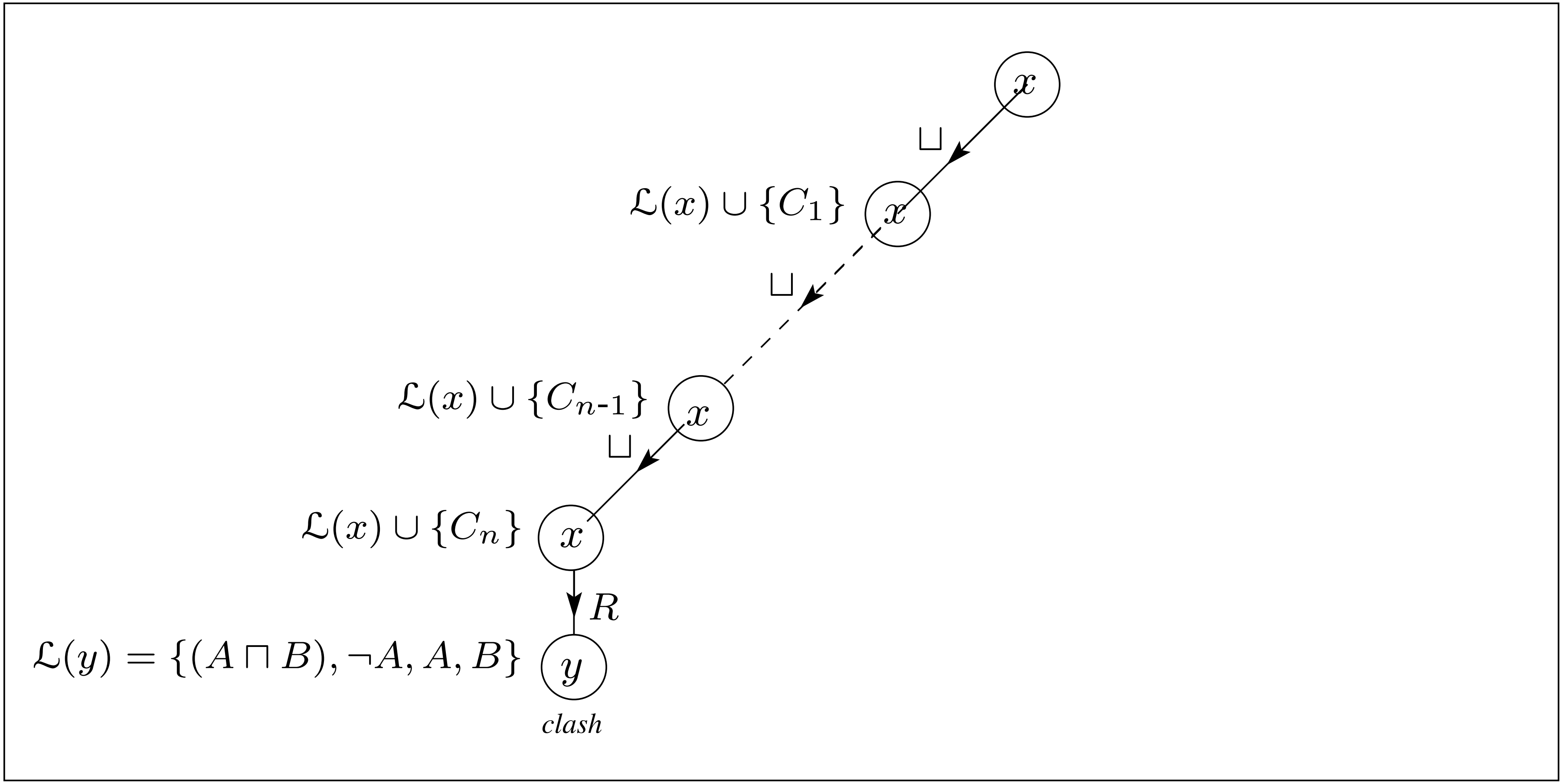

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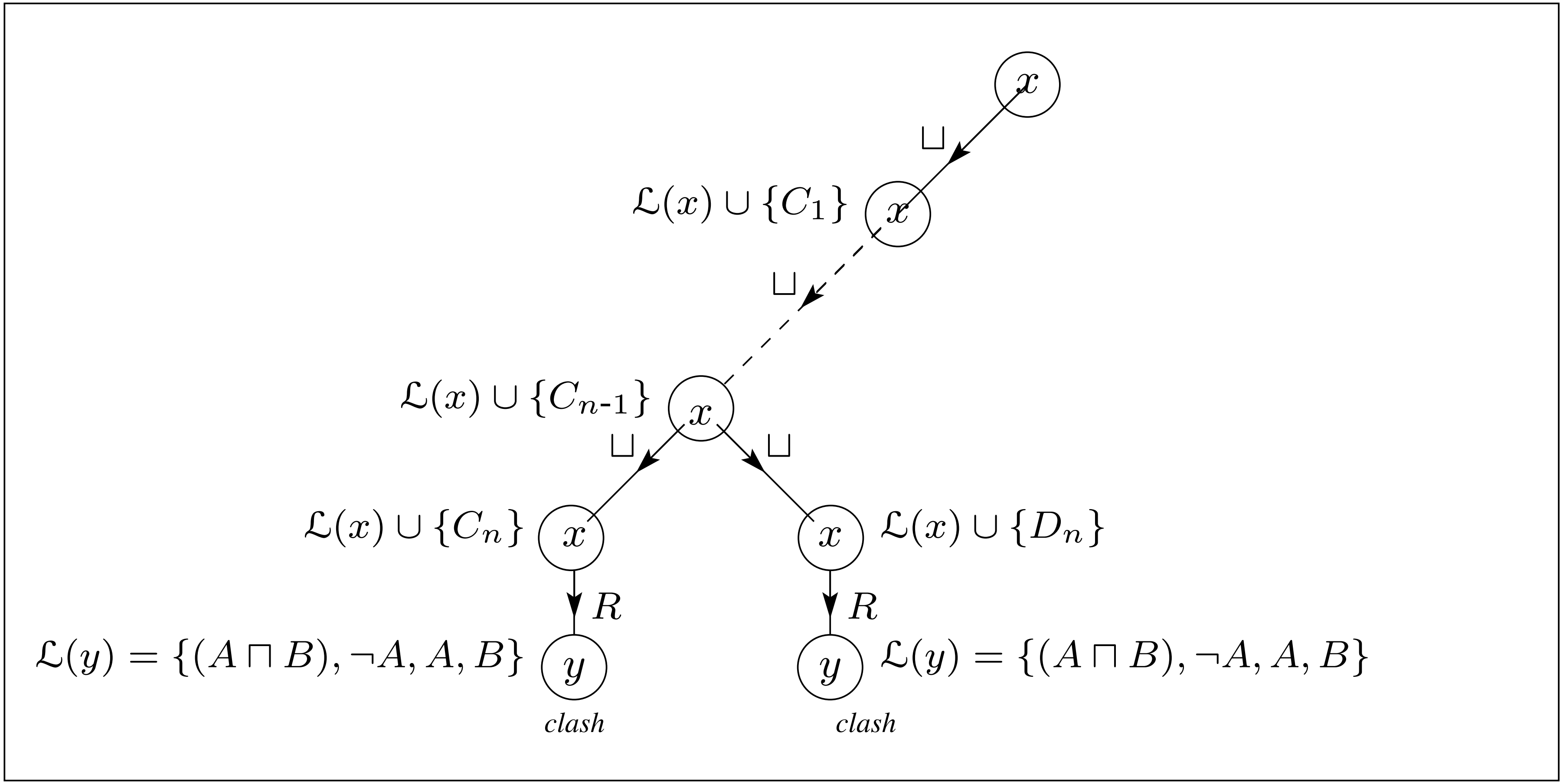

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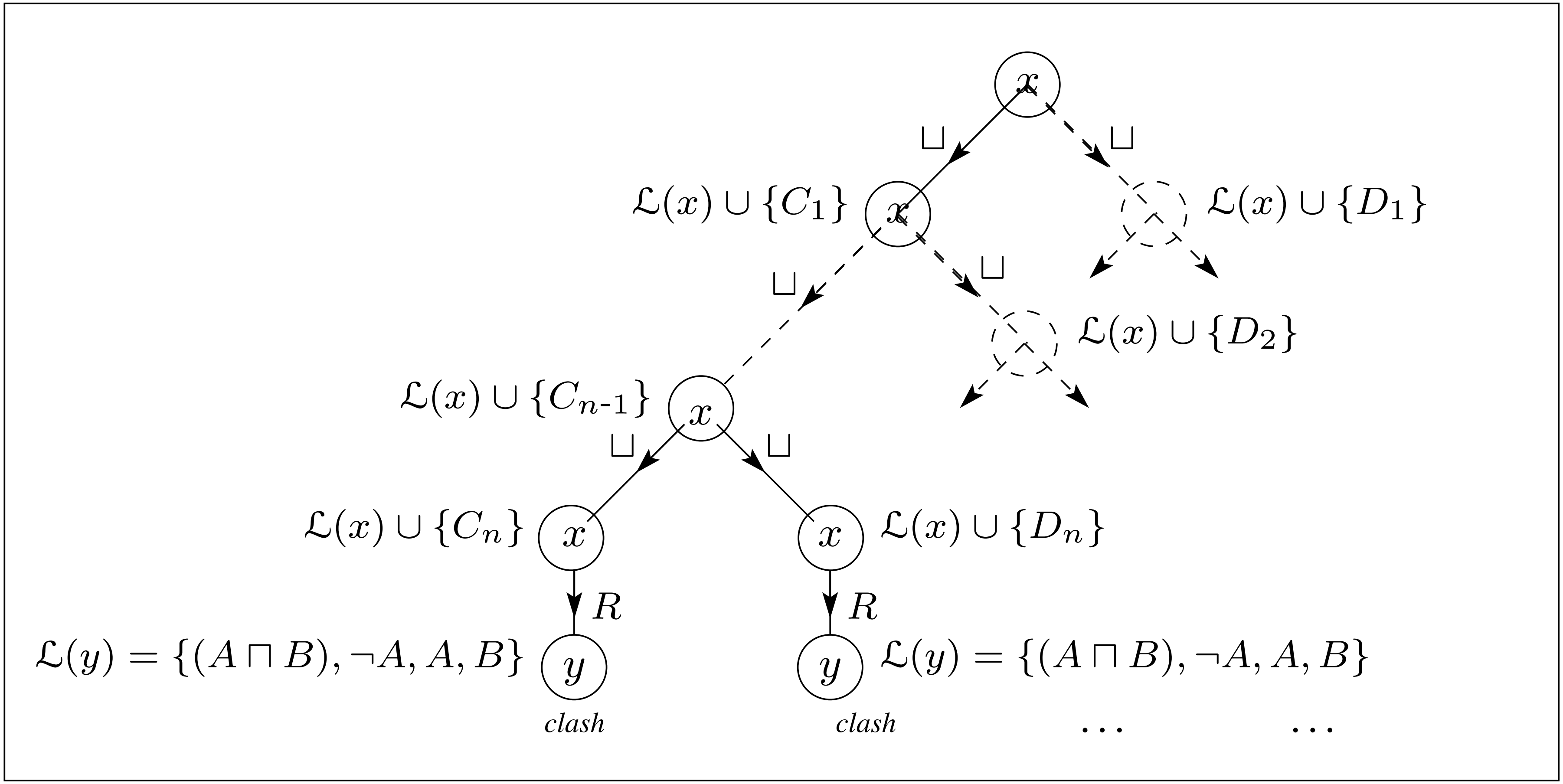

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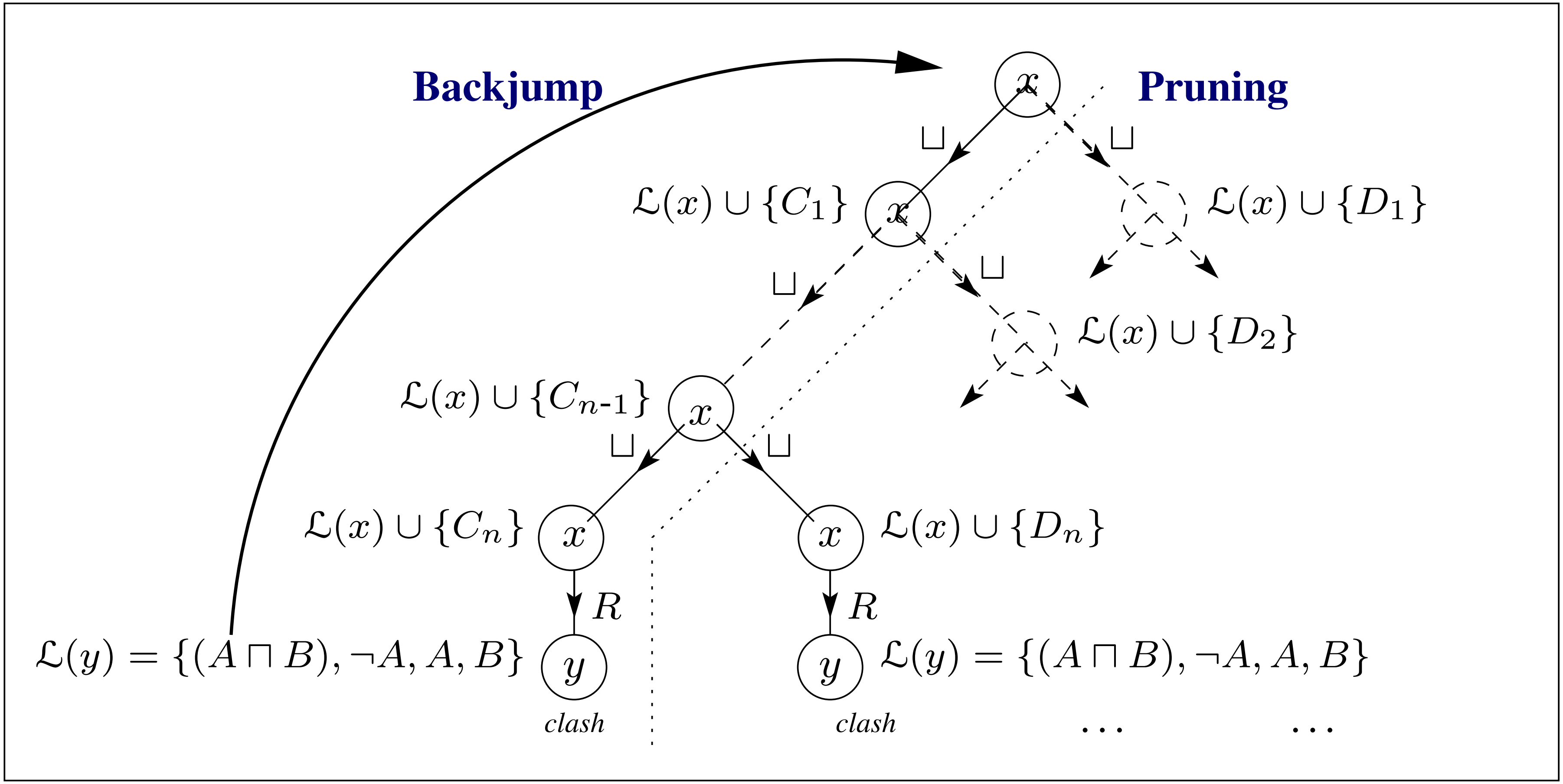

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  - Support for large scale ontological engineering and deployment

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  - Cerebra system (Network Inference), Racer system (Hamburg)

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- **Standard solution** is weaker semantics for nominals
  - Treat nominals as (disjoint) primitive classes
  - Loss of completeness/soundness

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- ☞ How can reasoners be developed/adapted for extended languages
  - Some existing work on language **fusions** and **hybrid** reasoners

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- Reasoning with **individuals**
  - **Deployment** of web ontologies will mean reasoning with (possibly very large numbers of) individuals/tuples
  - Unlikely that standard **Abox** techniques will be able to cope

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☞ Reasoning with **very large KBs**
- DL systems shown to work with ≈100k concept KB [Haarslev & Möller]
- But KB only exploited small part of DL language

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  - Justifications and proofs (e.g., of query results)
- “**Non-Standard Inferences**”, e.g., LCS, matching
  - To support ontology integration
  - To support “bottom up” design of ontologies

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- **DL Reasoning** based on tableau algorithms
- **Highly Optimised** implementations used in DL systems
- **Challenges** remain
  - Reasoning with full OWL language
  - (Convincing) demonstration(s) of scalability
  - New reasoning tasks
  - Development of (high quality) tools and infrastructure

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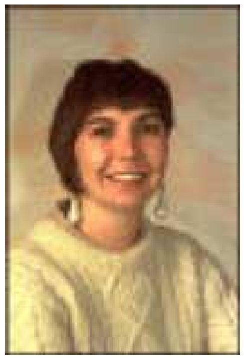

Resources

Slides from this talk

http://www.cs.man.ac.uk/~horrocks/Slides/Innsbruck-tutorial/

FaCT system (open source)

http://www.cs.man.ac.uk/FaCT/

OilEd (open source)

http://oiled.man.ac.uk/

OIL

http://www.ontoknowledge.org/oil/

W3C Web-Ontology (WebOnt) working group (OWL)

http://www.w3.org/2001/sw/WebOnt/

DL Handbook, Cambridge University Press

http://books.cambridge.org/0521781760.htm

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