Reasoning with Expressive Description Logics: Theory and Practice

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Talk Outline

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Introduction to Description Logics (DLs)

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- **Introduction to Description Logics (DLs)**
- **Reasoning techniques**

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- Introduction to Description Logics (DLs)
- Reasoning techniques
- Implementing DL systems

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- **Reasoning techniques**
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- **DL applications**
  - **Including demos** (time permitting)

Introduction to DLs

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- ☞ Closely related to **propositional modal logics**
- ☞ Also known as terminological logics, concept languages, etc.
- ☞ Key features of DLs are
  - Well defined semantics (they are logics)
  - Provision of inference services

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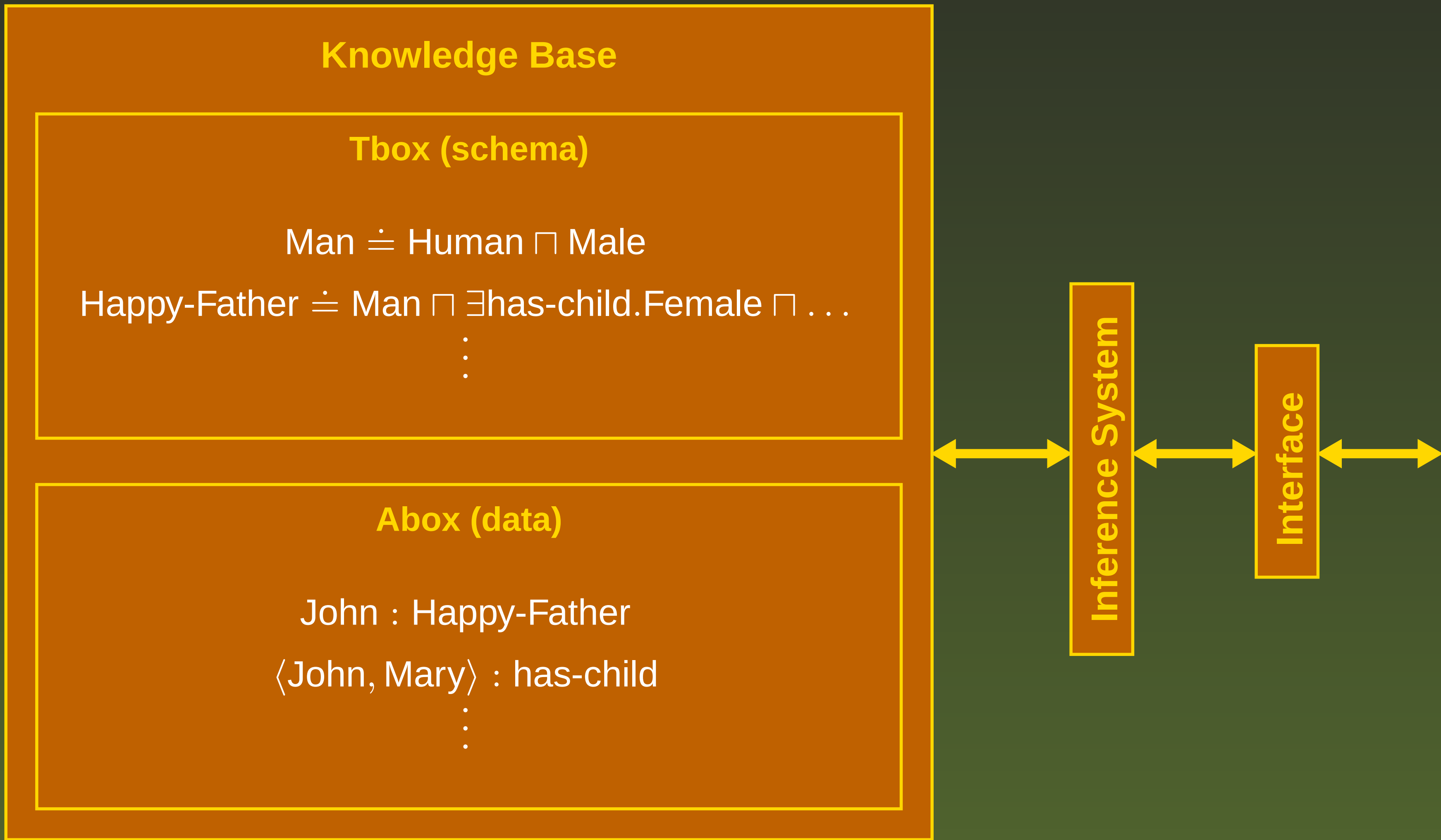
Database schema and query reasoning

- ☞ Schema design and query optimisation
- ☞ Interoperability and federation
- ☞ Query containment (w.r.t. schema)

DL System Architecture



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For example, concept **Happy Father** in $\mathcal{ALC}$:

$$\begin{array}{lll} \text{Man} & \sqcap & \exists\text{has-child.Male} \\ & \sqcap & \exists\text{has-child.Female} \\ & \sqcap & \forall\text{has-child.}(\text{Doctor} \sqcup \text{Lawyer}) \end{array}$$

DL Syntax and Semantics

Semantics given by **interpretation** $\mathcal{I} = (\Delta^{\mathcal{I}}, \cdot^{\mathcal{I}})$

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Constructor	Syntax	Example	Semantics
atomic concept	A	Human	$A^{\mathcal{I}} \subseteq \Delta^{\mathcal{I}}$
atomic role	R	has-child	$R^{\mathcal{I}} \subseteq \Delta^{\mathcal{I}} \times \Delta^{\mathcal{I}}$
and for C, D concepts and R a role name			
conjunction	$C \sqcap D$	Human $\sqcap$ Male	$C^{\mathcal{I}} \cap D^{\mathcal{I}}$
disjunction	$C \sqcup D$	Doctor $\sqcup$ Lawyer	$C^{\mathcal{I}} \cup D^{\mathcal{I}}$
negation	$\neg C$	$\neg$Male	$\Delta^{\mathcal{I}} \setminus C$
exists restr.	$\exists R.C$	$\exists$has-child.Male	$\{x \mid \exists y.\langle x, y\rangle \in R^{\mathcal{I}} \wedge y \in C^{\mathcal{I}}\}$
value restr.	$\forall R.C$	$\forall$has-child.Doctor	$\{x \mid \forall y.\langle x, y\rangle \in R^{\mathcal{I}} \implies y \in C^{\mathcal{I}}\}$

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number restr.	$\geqslant nR$	$\geqslant 3$ has-child	$\{x \mid \lvert\{y.\langle x,y\rangle \in R^{\mathcal{I}}\}\rvert \geqslant n\}$
	$\leqslant nR$	$\leqslant 1$ has-mother	$\{x \mid \lvert\{y.\langle x,y\rangle \in R^{\mathcal{I}}\}\rvert \leqslant n\}$
inverse role	R^-	has-child$^-$	$\{\langle x,y\rangle \mid \langle y,x\rangle \in R^{\mathcal{I}}\}$
trans. role	R^*	has-child*	$(R^{\mathcal{I}})^*$
concrete domain	$f_1,\ldots,f_n.P$	earns spends $<$	$\{x \mid P(f_1^{\mathcal{I}},\ldots,f_n^{\mathcal{I}})\}$

$\vdots$

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  - $A \doteq C$, $A \sqsubseteq C$
  - $\text{Father} \doteq \text{Man} \sqcap \exists\text{has-child.Human}$
  - $\text{Human} \sqsubseteq \text{Animal} \sqcap \text{Biped}$

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- **Inclusion** (GCI) axioms assert subsumption relations
  - $C \sqsubseteq D$ (note $C \doteq D$ equivalent to $C \sqsubseteq D$ and $D \sqsubseteq C$)
  - $\exists \mathsf{has\text{-}degree}.\mathsf{Masters} \sqsubseteq \exists \mathsf{has\text{-}degree}.\mathsf{Bachelors}$

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An interpretation $\mathcal{I}$ **satisfies**

- $C \doteq D$ iff $C^{\mathcal{I}} = D^{\mathcal{I}}$ $\quad$ $C \sqsubseteq D$ iff $C^{\mathcal{I}} \subseteq D^{\mathcal{I}}$
- A **Tbox** $\mathcal{T}$ iff it satisfies every axiom in $\mathcal{T}$ ($\mathcal{I} \models \mathcal{T}$)

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$$\langle a, b \rangle : R$$

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An **Abox** $\mathcal{A}$ iff it satisfies every axiom in $\mathcal{A}$ ($\mathcal{I} \models \mathcal{A}$)

A **KB** $\Sigma = \langle \mathcal{T}, \mathcal{A} \rangle$ iff it satisfies both $\mathcal{T}$ and $\mathcal{A}$ ($\mathcal{I} \models \Sigma$)

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Problems are **closely related**:

$C \sqsubseteq_{\mathcal{T}} D$	iff	$C \sqcap \neg D$ is inconsistent w.r.t. $\mathcal{T}$
C is consistent w.r.t. $\mathcal{T}$	iff	$C \not\sqsubseteq_{\mathcal{T}} A \sqcap \neg A$

Reasoning Techniques

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  - **Blocking** ensures termination (with expressive DLs)

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w

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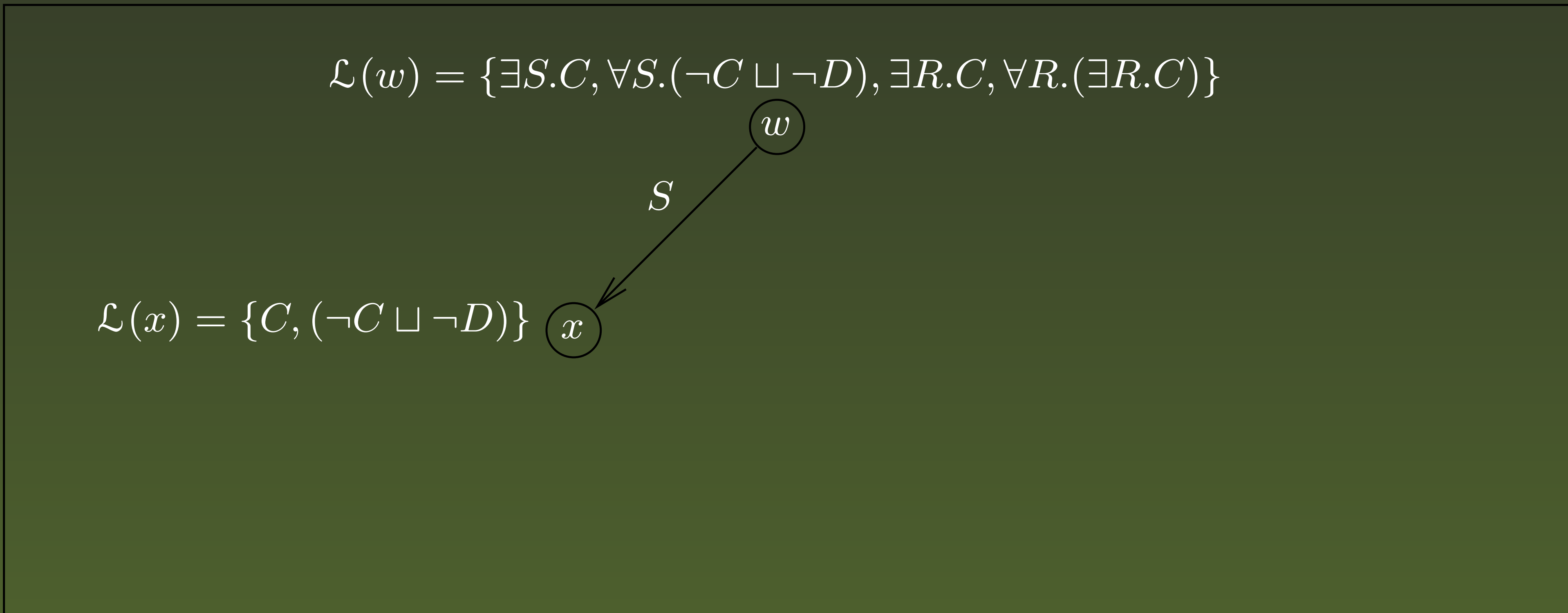

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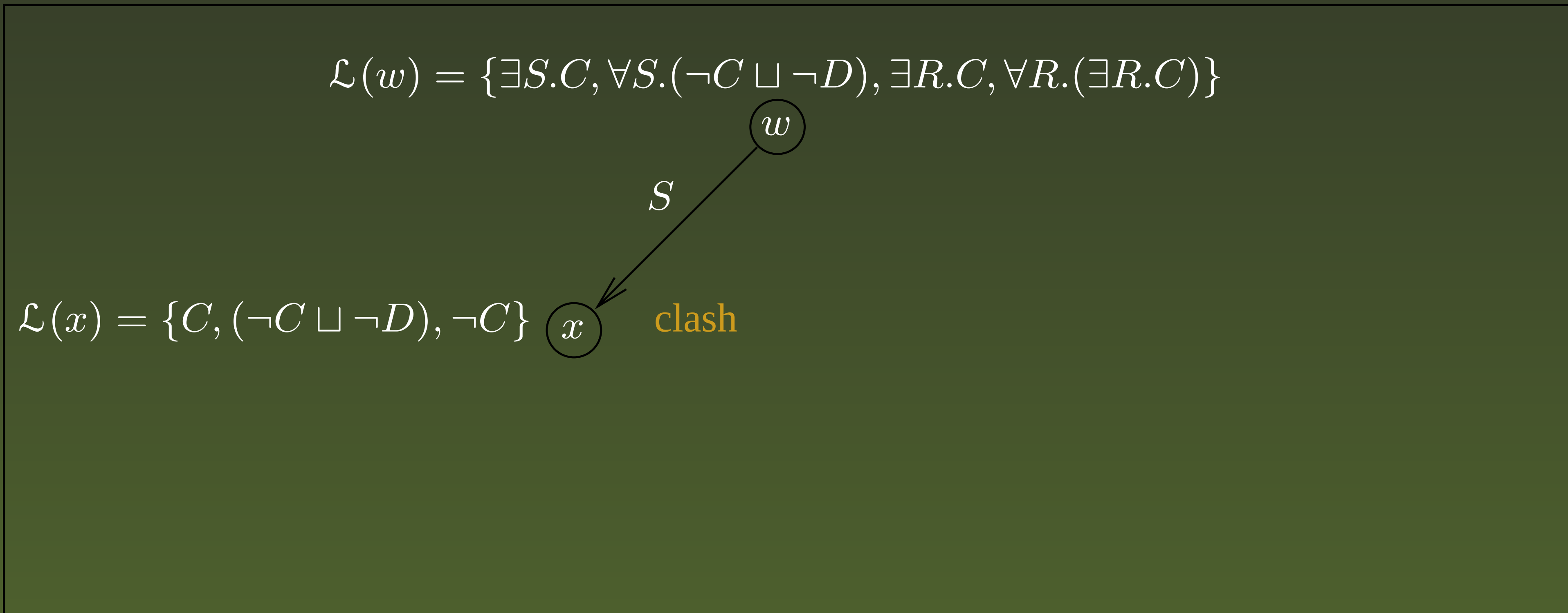

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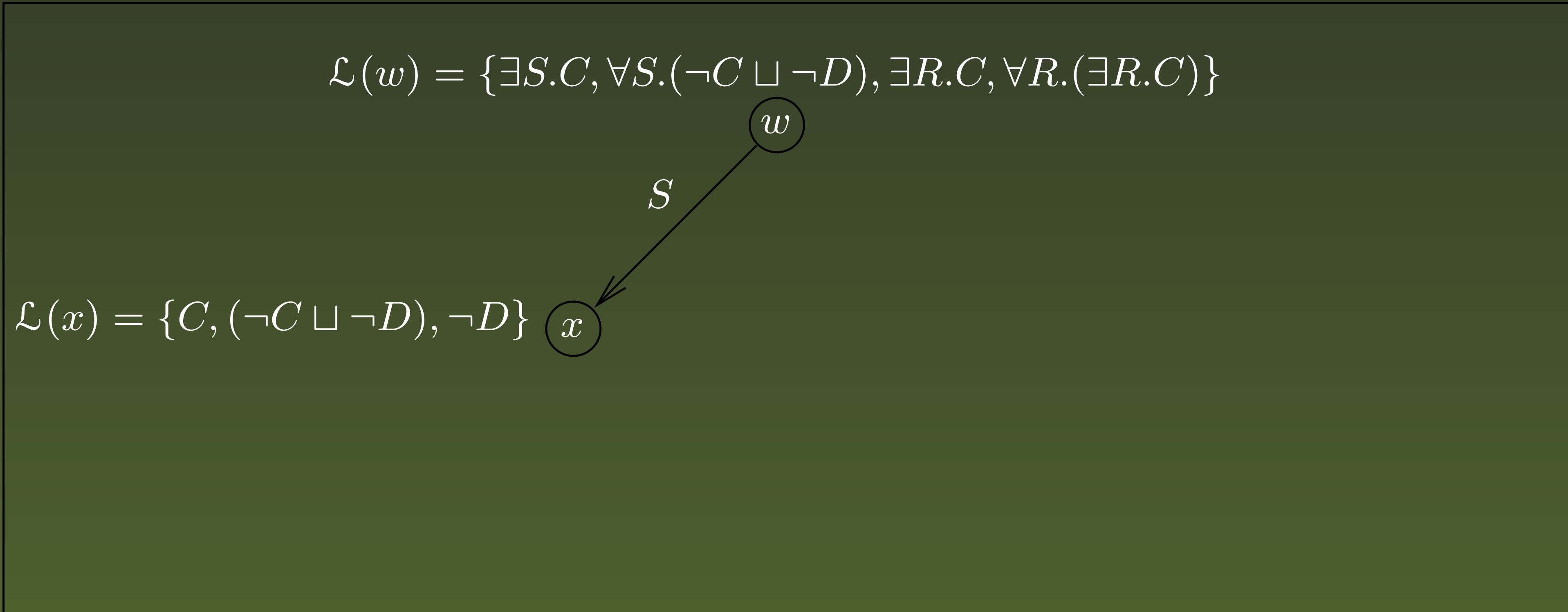

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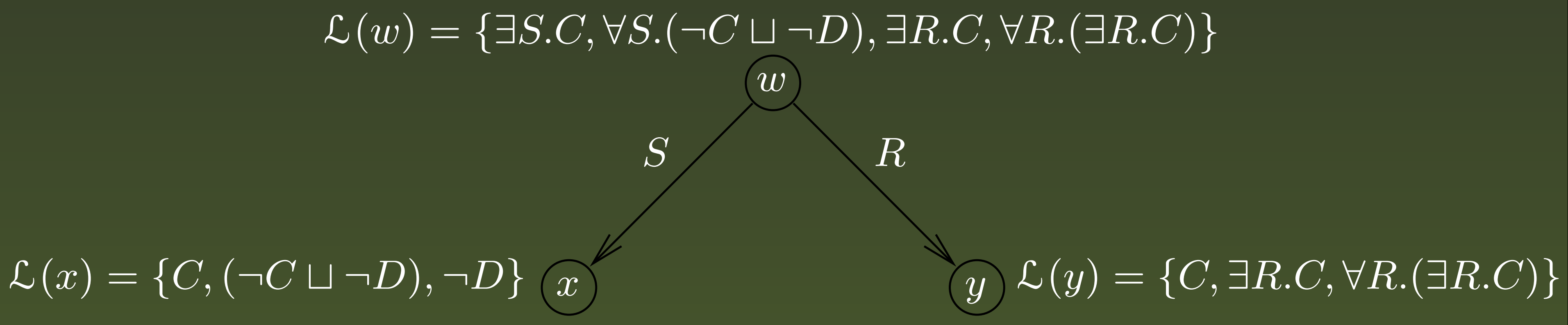

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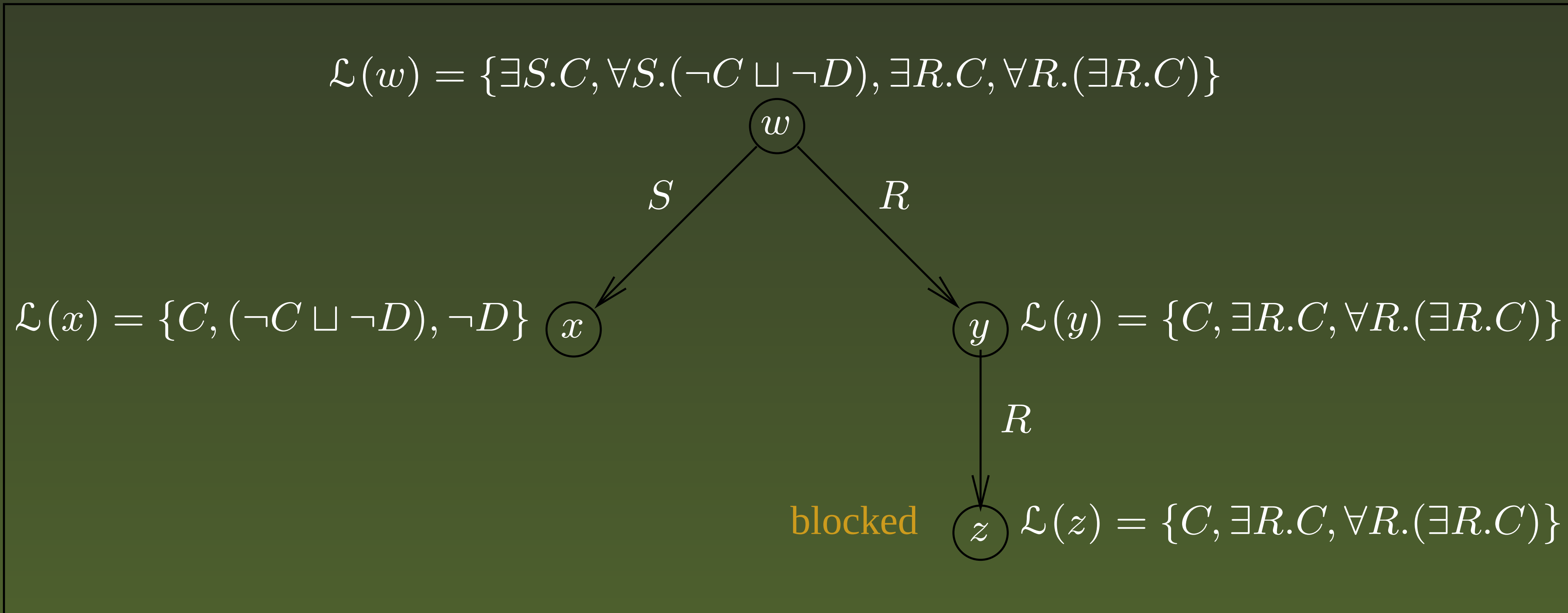

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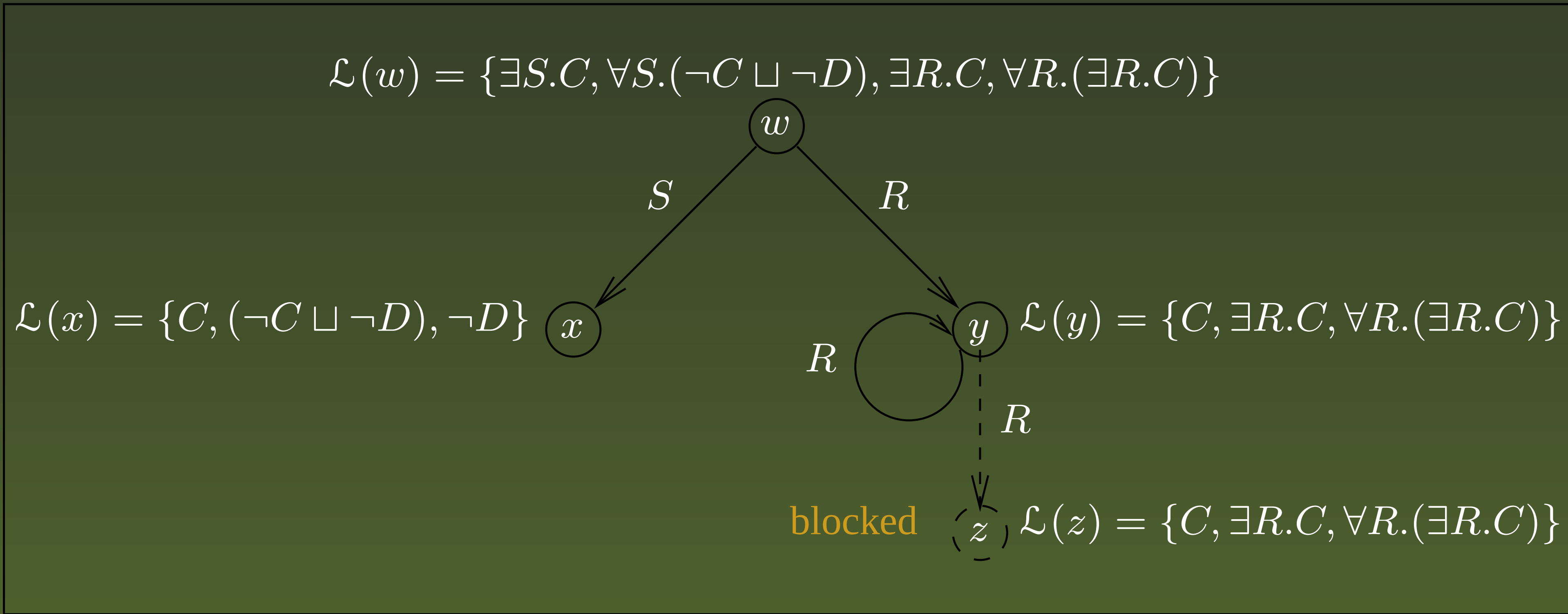

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- Concrete domains
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- ☞ Extend **expansion rules** and use more sophisticated **blocking** strategy
- ☞ Forest instead of Tree (for Aboxes)

Implementing DL Systems

Naive Implementations

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    - ➜ Highly **optimised implementation**

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  - Recent DL research has addressed this problem (with considerable success)

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  - But often generally applicable to search based algorithms

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E.g.:

$\{\text{HappyFather}, \neg\text{HappyFather}\} \longrightarrow$ **clash**

$\{\forall\text{has-child}.(\text{Doctor} \sqcup \text{Lawyer}), \exists\text{has-child}.(\neg\text{Doctor} \sqcap \neg\text{Lawyer})\} \longrightarrow$ **search**

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  - Performance improvements with GALEN KB again **too large to measure**

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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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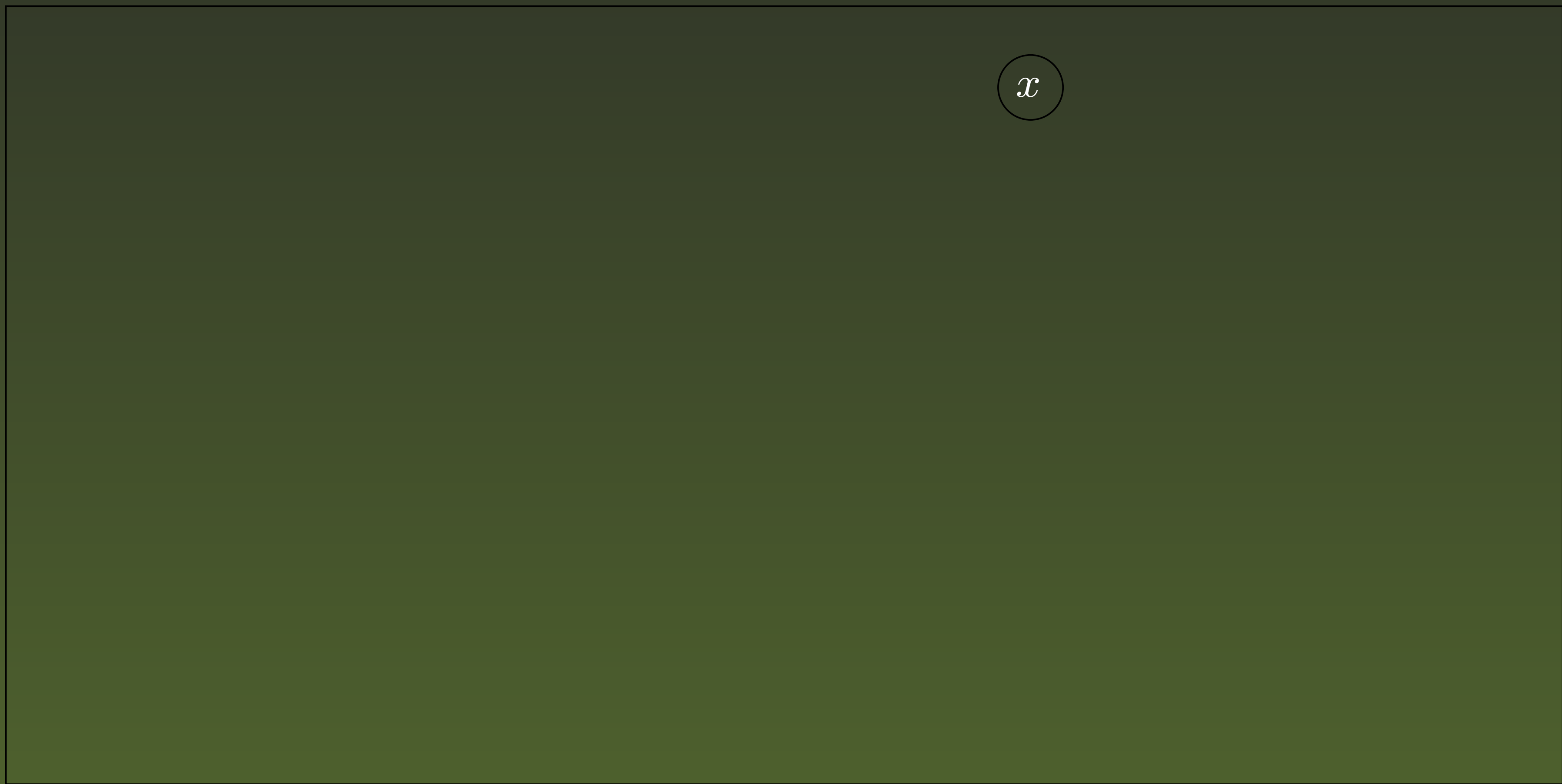

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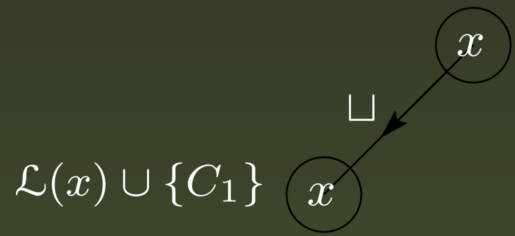

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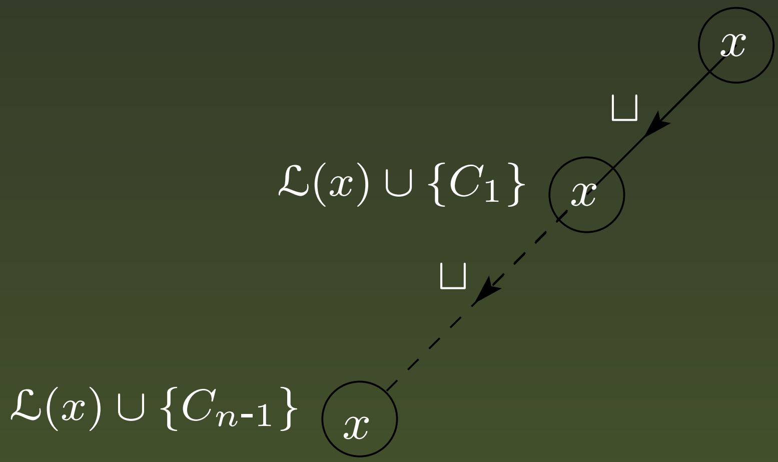

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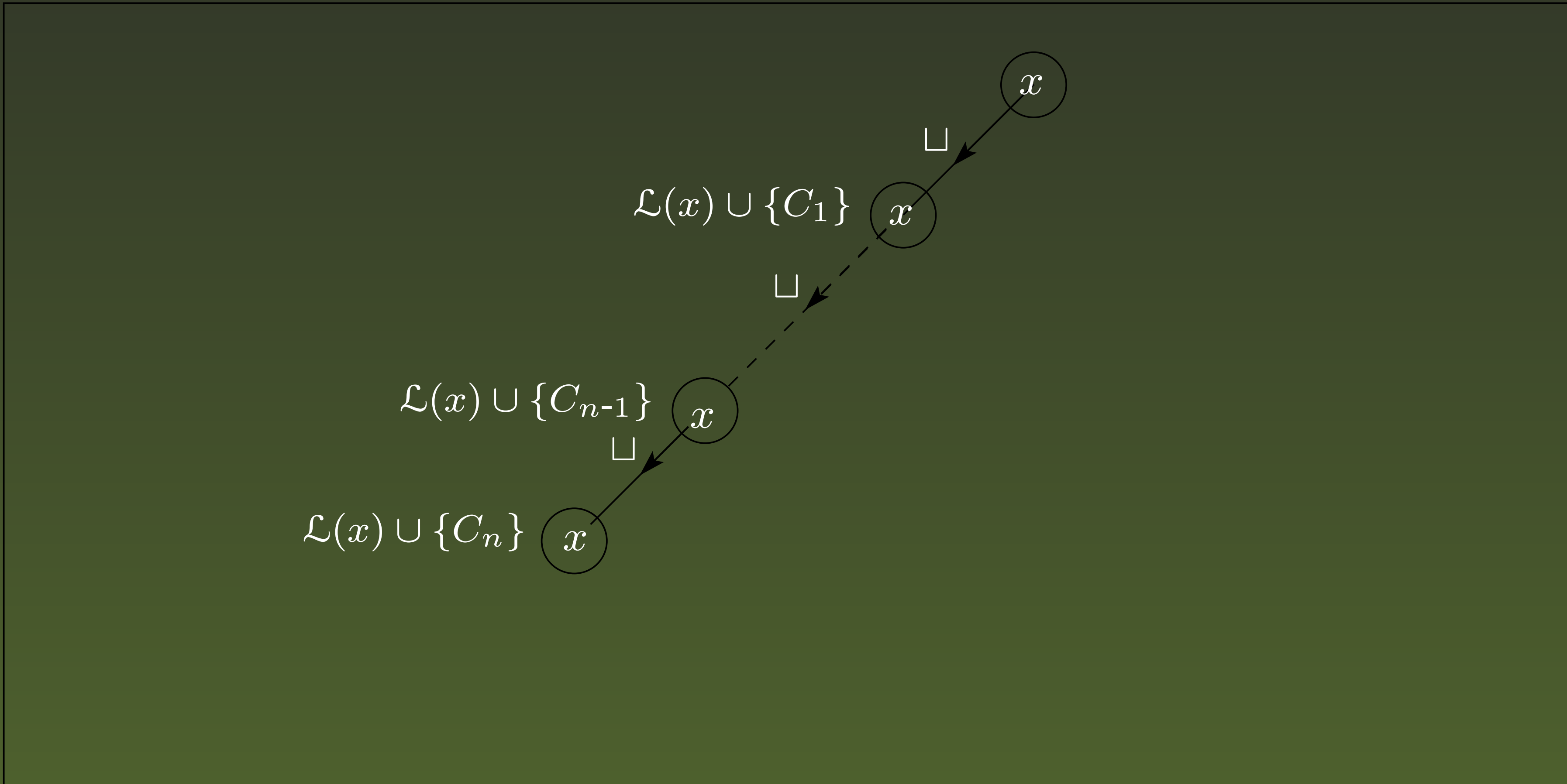

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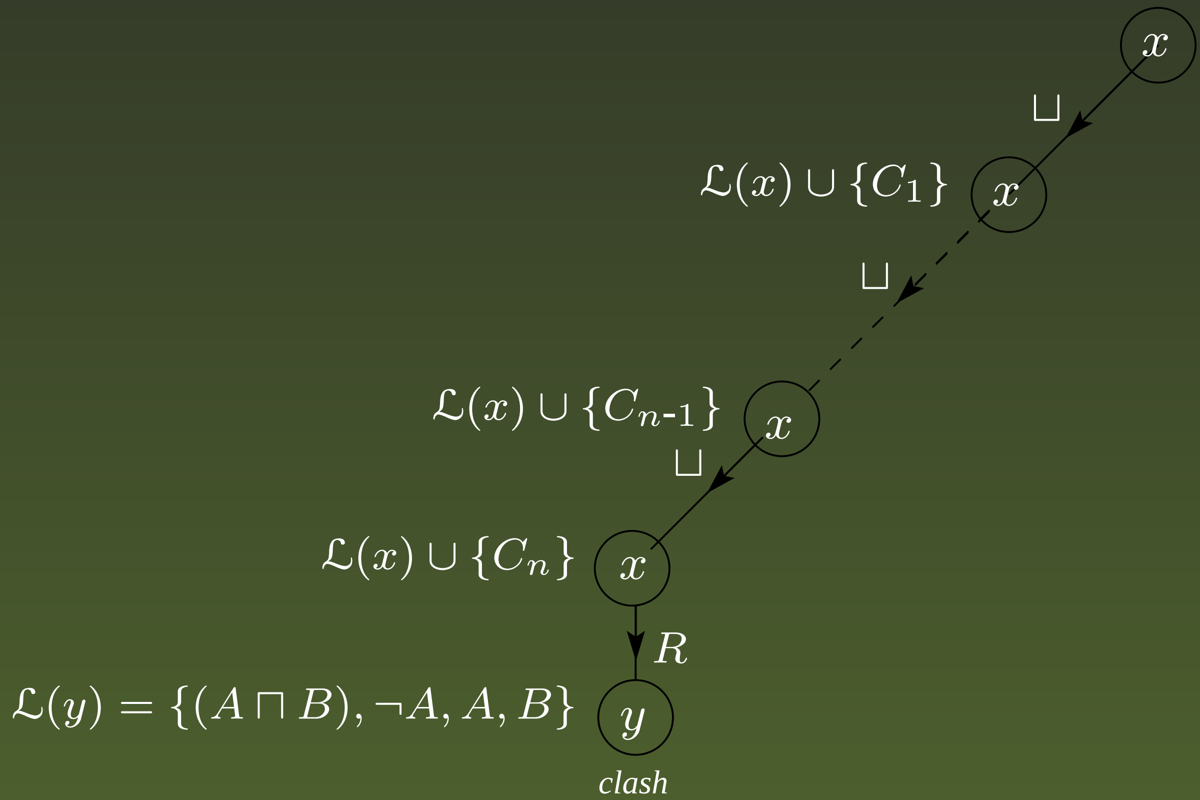

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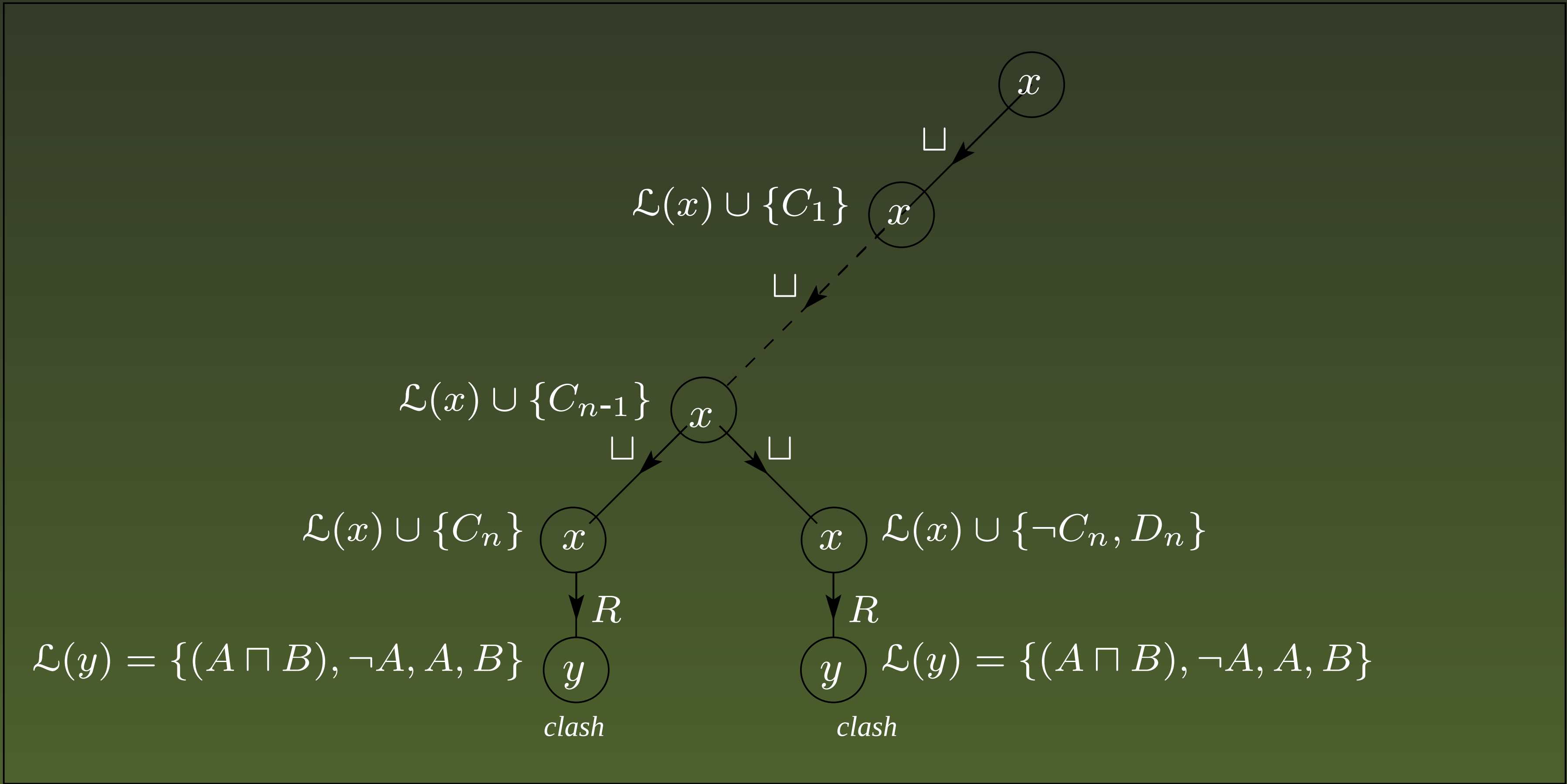

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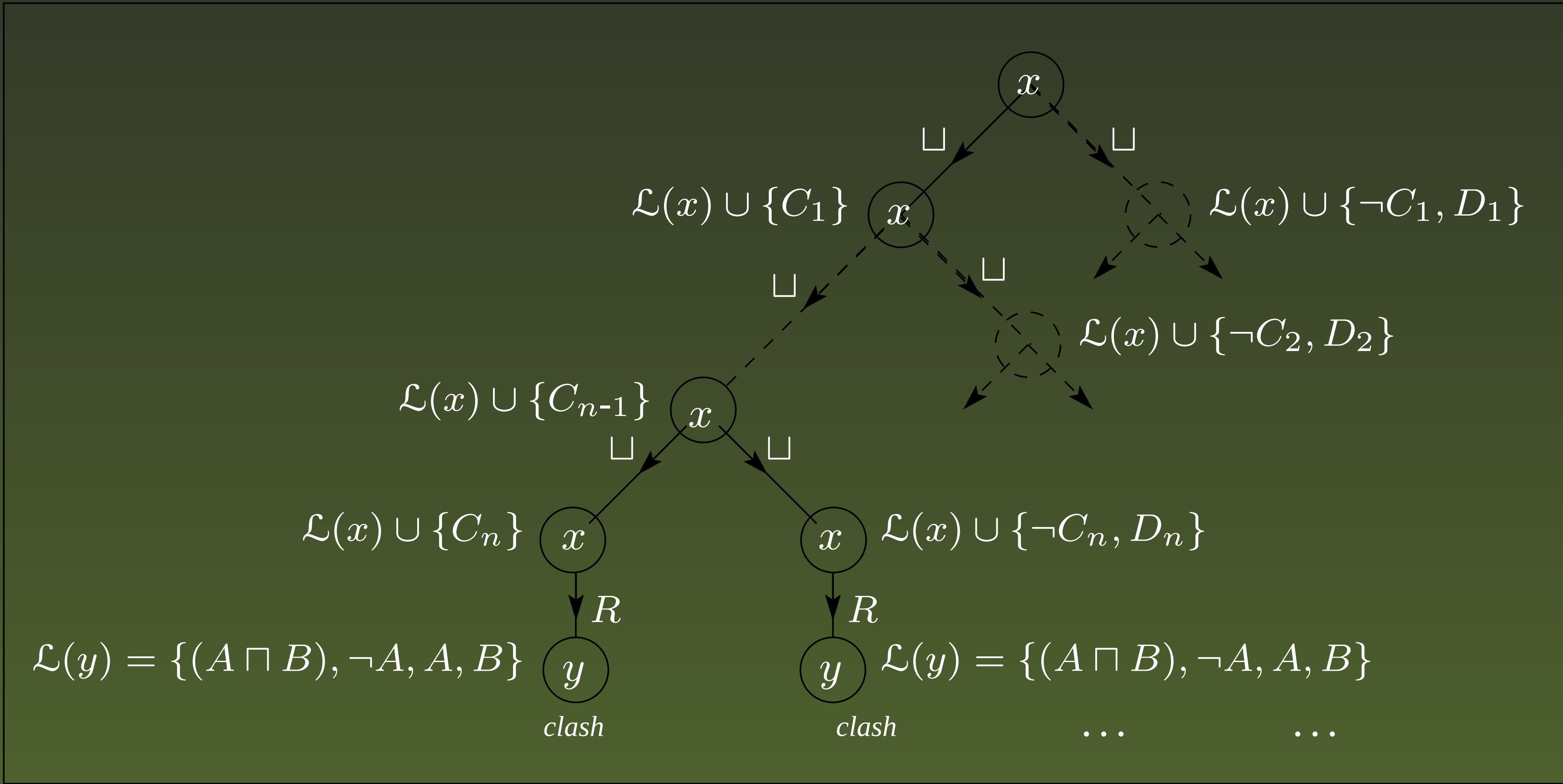

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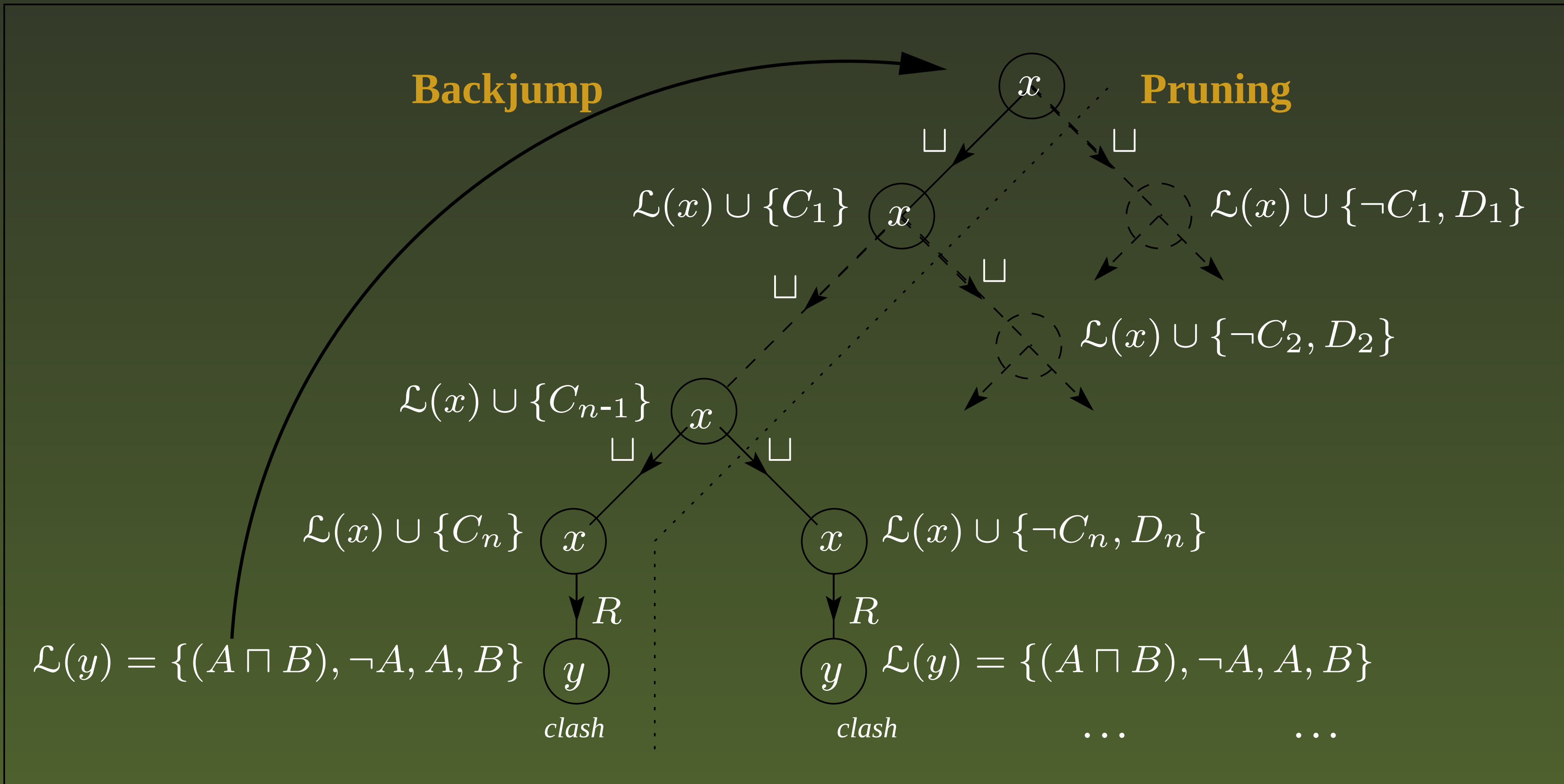

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DL applications

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- ☞ Needed expressive DL **and** efficient reasoning
  - Descriptions use transitive roles, inverses, GCIs etc.
  - Even prototype KB is very large ($\approx$3,000 concepts)
  - Existing (incomplete) classifier took $\approx$24 hours to classify KB
  - FaCT system (sound and complete) takes $\approx$60s

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- ☞ E.g., **OilEd** ontology editor
  - Frame based interface (e.g., Protegé, OntoEdit)
  - Extended to capture whole of OIL/DAML+OIL languages
  - Reasoning support from FaCT (via CORBA interface)

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  $\mathsf{Stomach\text{-}Ulcer} \sqsubseteq \exists \mathsf{hasLocation.Lining\text{-}Of\text{-}Stomach}$

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- Inverse roles capture e.g. causes/causedBy relationship

  $\mathsf{Death} \sqcap \exists \mathsf{causedBy.Smoking} \sqsubseteq \mathsf{PrematureDeath}$

  $\Rightarrow \mathsf{Smoking} \sqsubseteq \mathsf{CauseOfPrematureDeath}$

- Cardinality restrictions add consistency constraints

  $\mathsf{BloodPressure} \sqsubseteq \exists \mathsf{hasValue.}(\mathsf{High} \sqcup \mathsf{Low}) \sqcap \leqslant 1 \mathsf{hasValue}$ plus

  $\mathsf{High} \sqsubseteq \neg \mathsf{Low} \Rightarrow \mathsf{HighLowBloodPressure} \sqsubseteq \bot$

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- E.g., **I.COM** Intelligent Conceptual Modelling tool (Enrico Franconi)
  - Uses FaCT system to provide reasoning support for EER

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  - Web standard ontology language will be DL based

Resources

Slides from this talk

`www.cs.man.ac.uk/~horrocks/Slides/leipzig-jun-01.pdf`

FaCT system

`www.cs.man.ac.uk/fact`

OIL

`www.ontoknowledge.org/oil/`

DAML+OIL

`www.daml.org/language/`

OilEd

`img.cs.man.ac.uk/oil`

I.COM

`www.cs.man.ac.uk/~franconi/icom/`

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