How to use cvc5 Effectively

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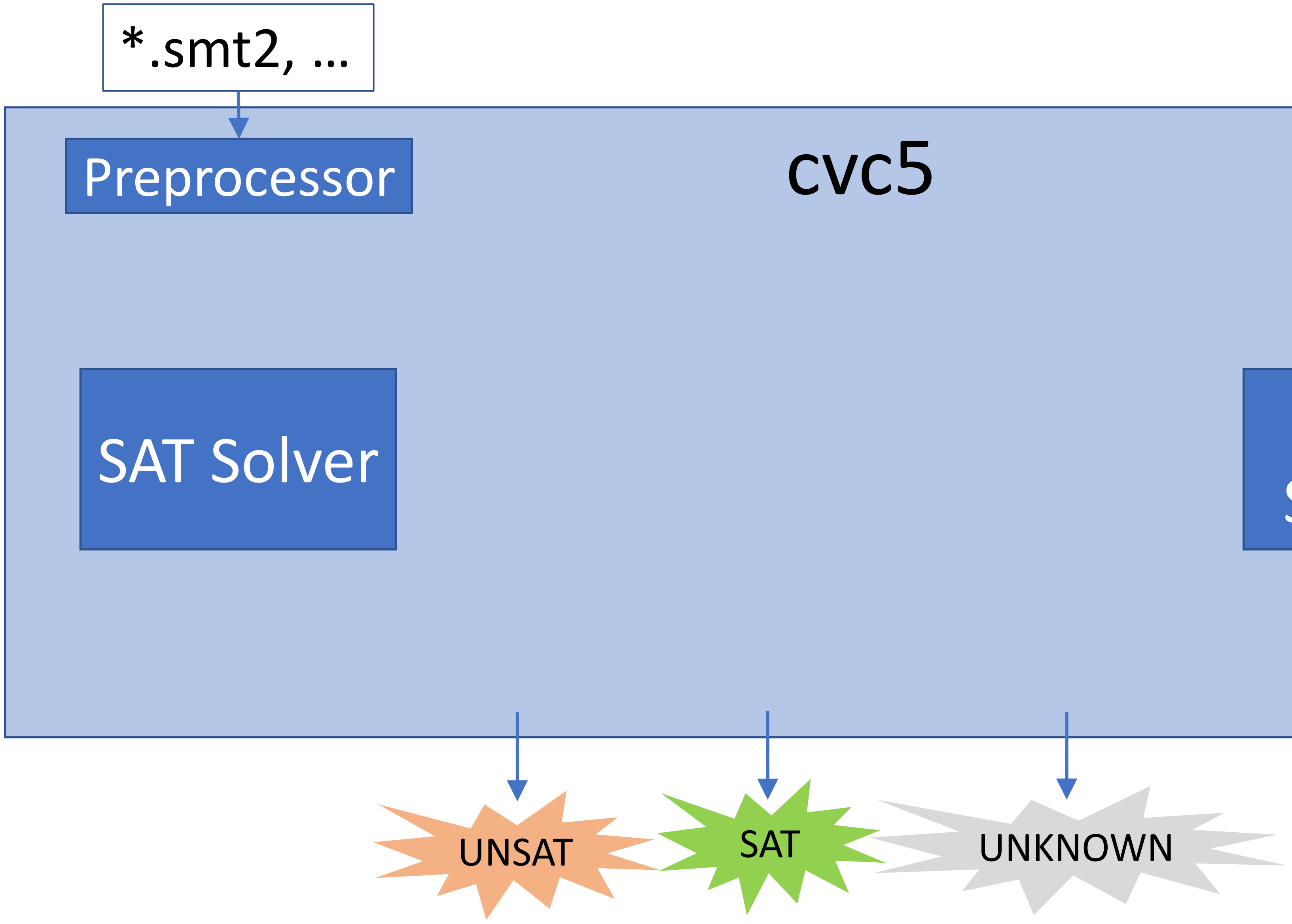
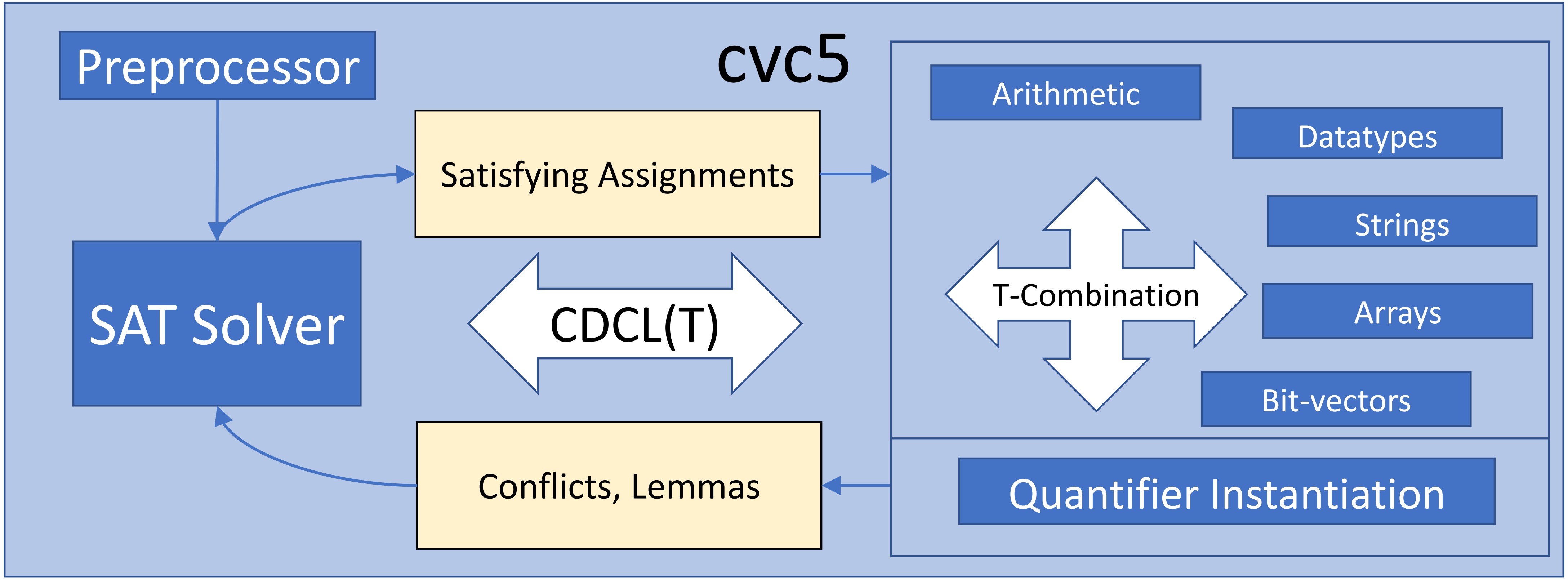
Overview

- cvc5: a state-of-the-art SMT solver for verification
  - Supports many techniques for quantified formulas
  - Combined with a wide array of theory solvers
- Interfaces for when things go *right*
- Interfaces for when things go *wrong*

Architecture of cvc5



Architecture of cvc5



Landscape of Quantifier Strategies in cvc5

General purpose

Domain Specific

Lightweight

Heavyweight

⇒Many verification applications rely on *quantifier instantiation*

- cvc5 supports many variants

Landscape of Quantifier Strategies in cvc5

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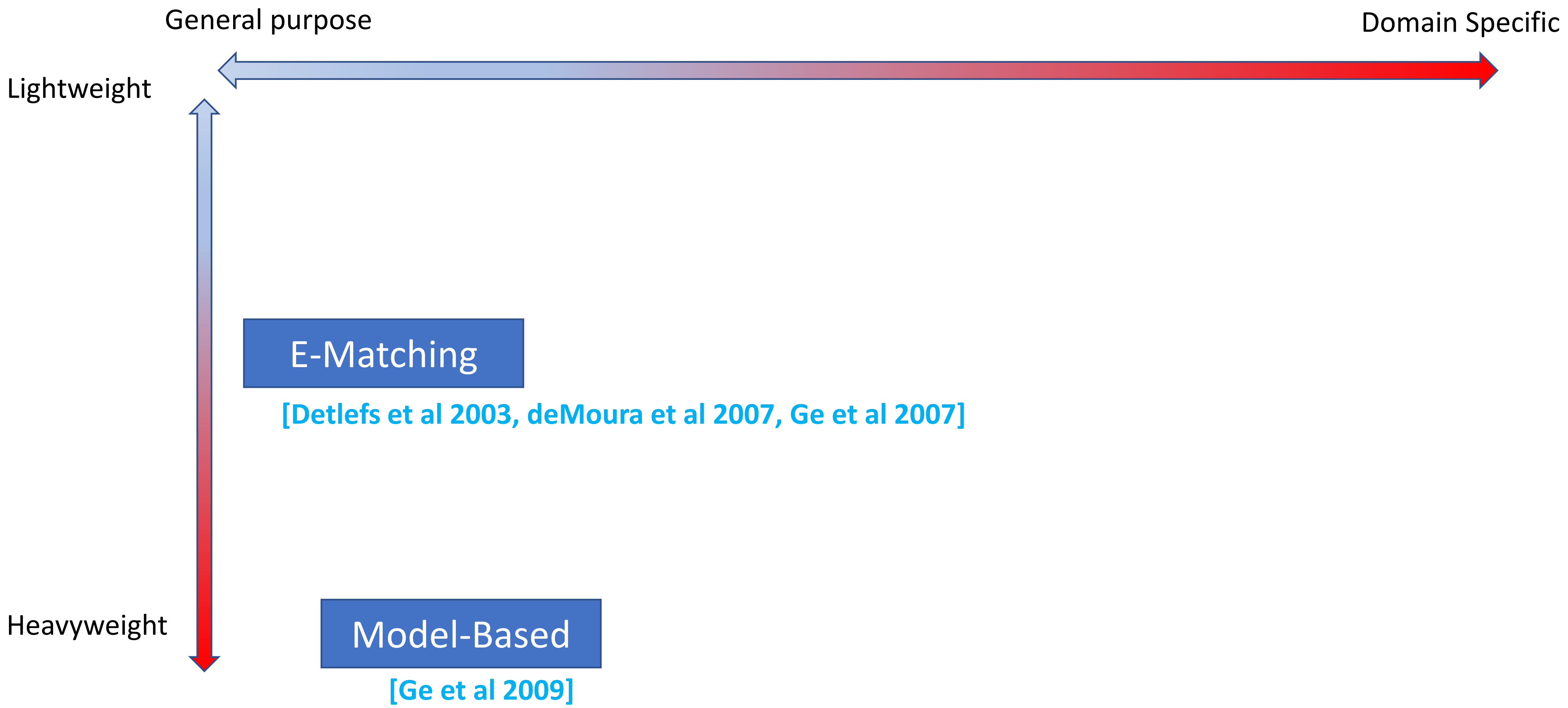

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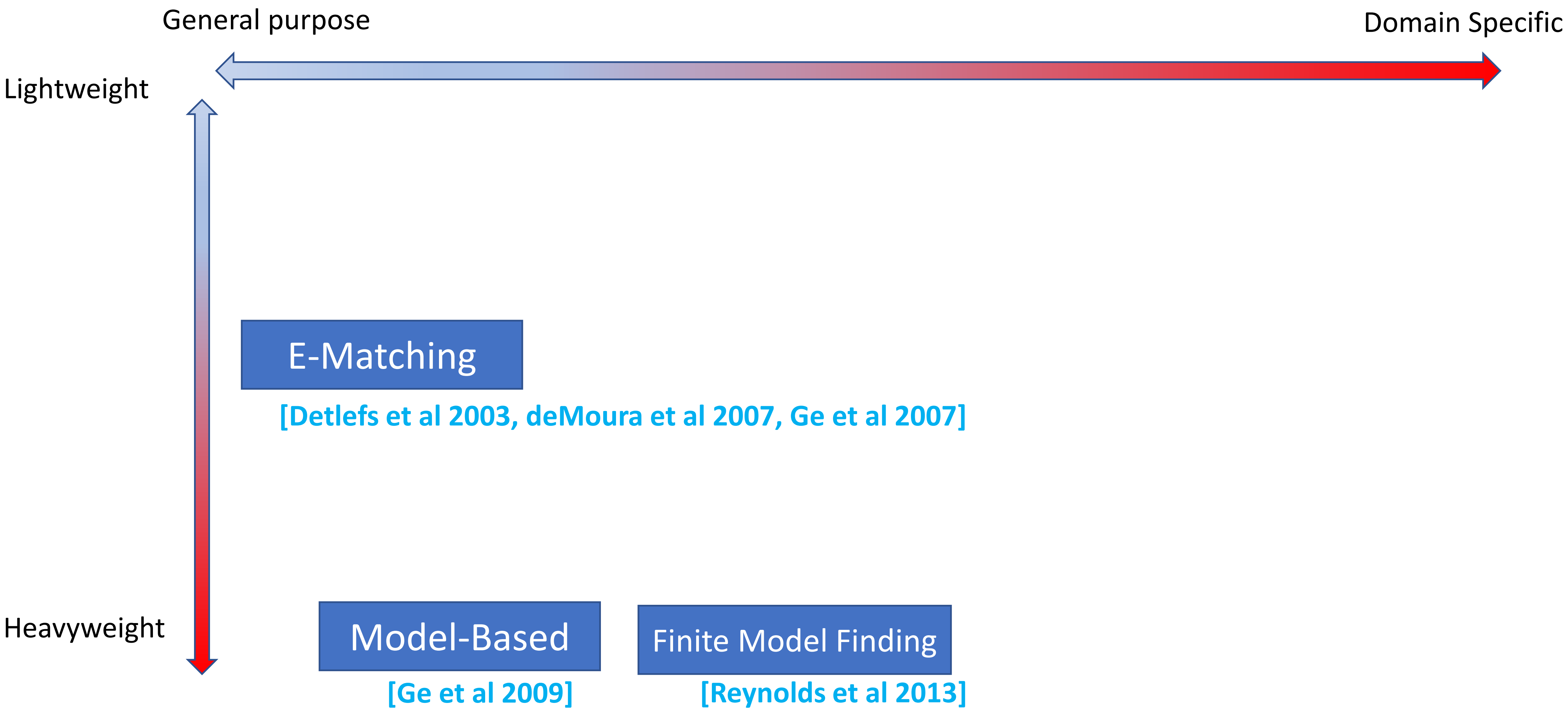


Landscape of Quantifier Strategies in cvc5

General purpose

Domain Specific

Lightweight

Conflict-Based

[Reynolds et al 2014,Barbosa et al 2017]

E-Matching

[Detlefs et al 2003, deMoura et al 2007, Ge et al 2007]

Heavyweight

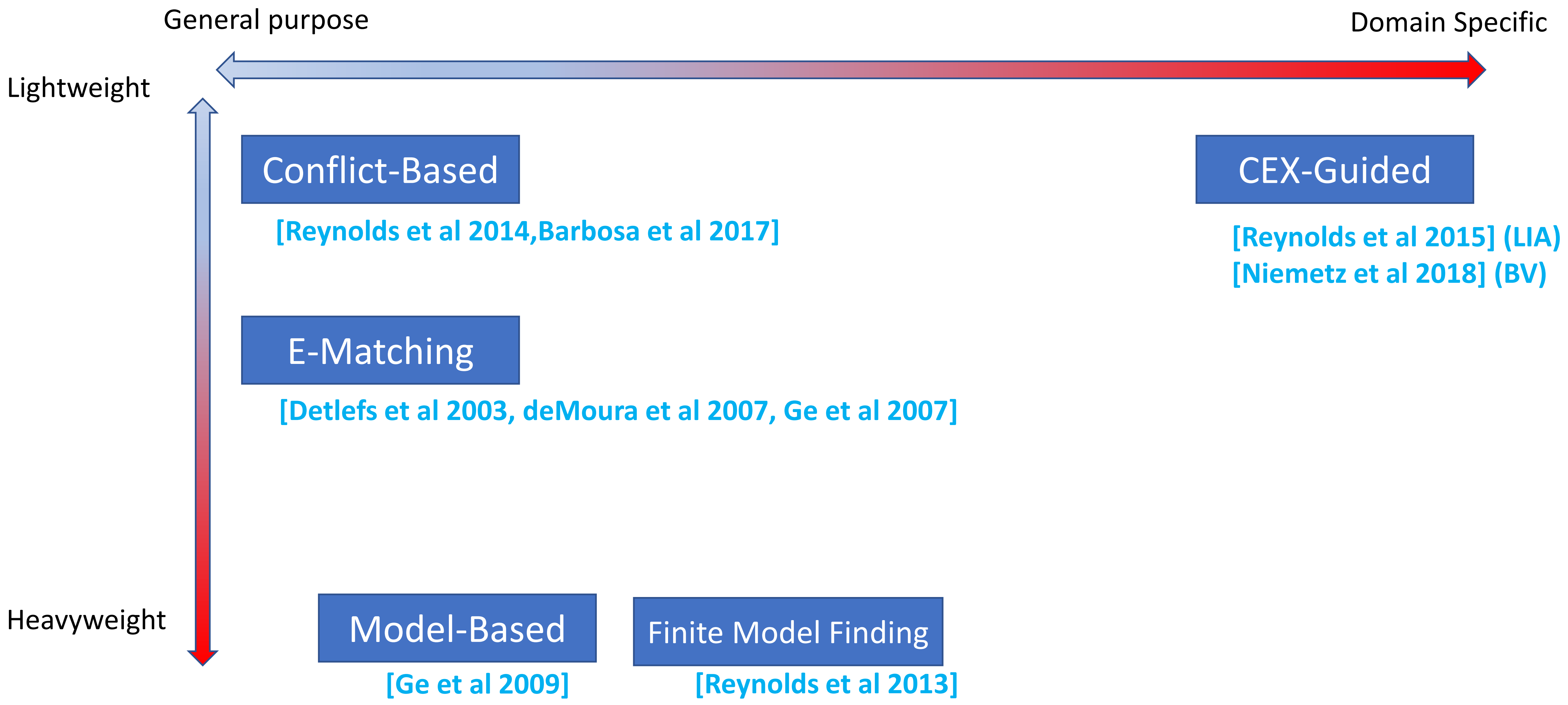
Model-Based

[Ge et al 2009]

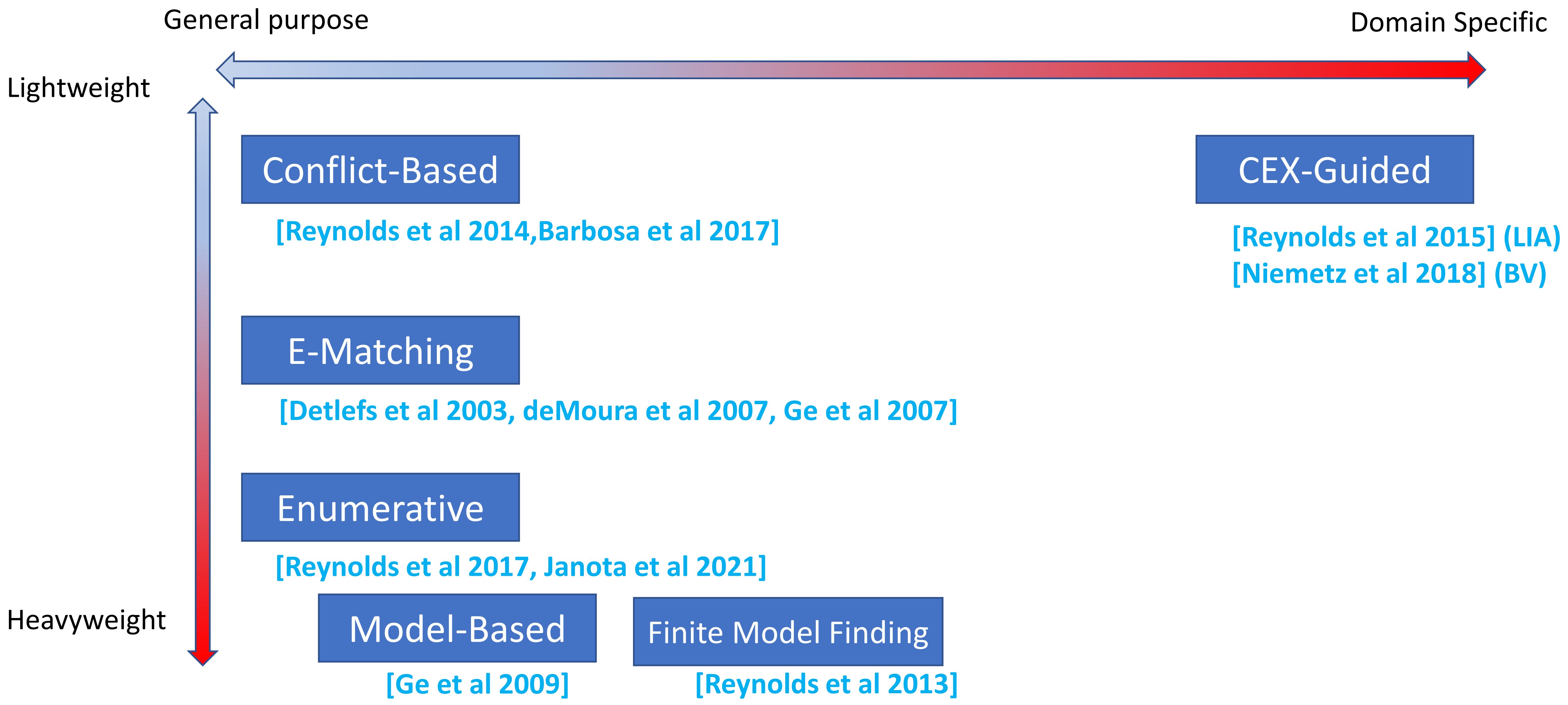
Finite Model Finding

[Reynolds et al 2013]

Landscape of Quantifier Strategies in cvc5



Landscape of Quantifier Strategies in cvc5



Landscape of Quantifier Strategies in cvc5

General purpose ⟷ Domain Specific

Lightweight ↕ Heavyweight

Conflict-Based
[Reynolds et al 2014,Barbosa et al 2017]

CEX-Guided
[Reynolds et al 2015] (LIA)
[Niemetz et al 2018] (BV)

E-Matching
[Detlefs et al 2003, deMoura et al 2007, Ge et al 2007]

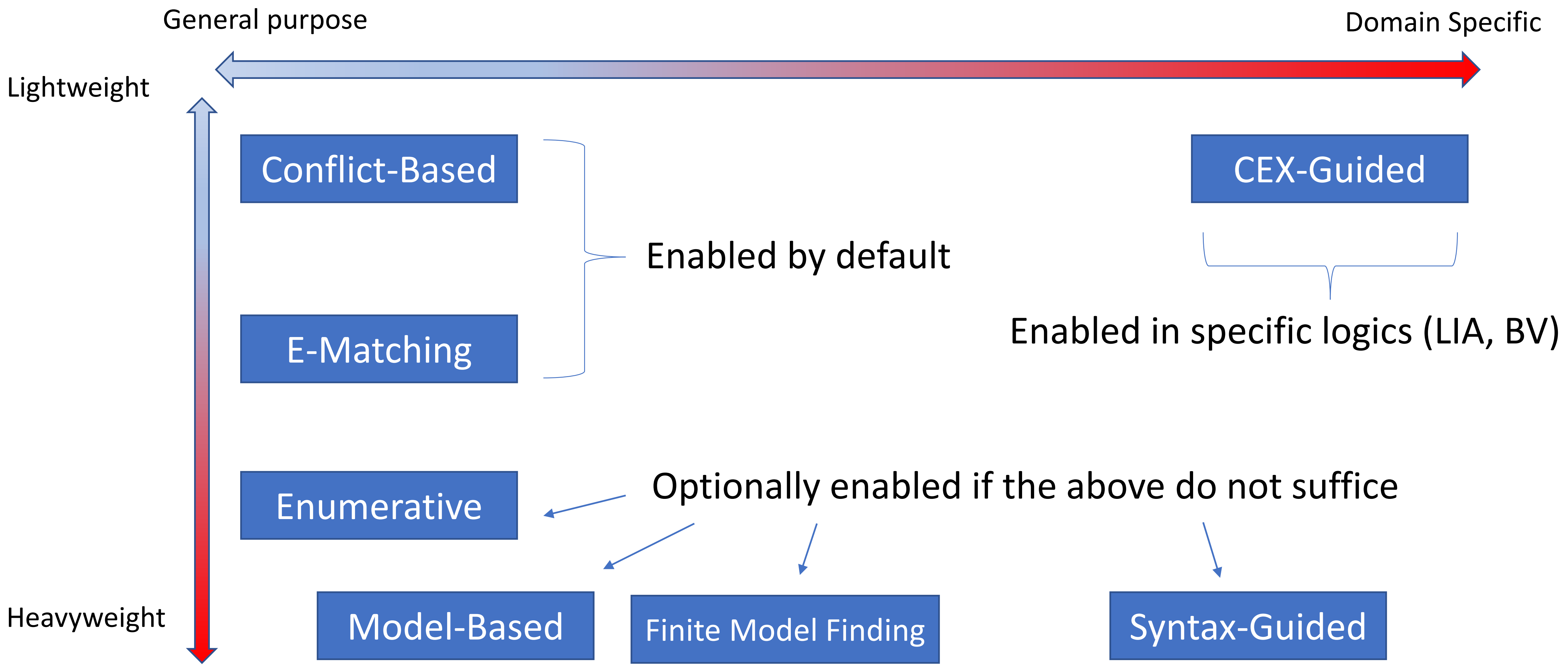
Enumerative
[Reynolds et al 2017, Janota et al 2021]

Model-Based
[Ge et al 2009]

Finite Model Finding
[Reynolds et al 2013]

Syntax-Guided
[Niemetz et al 2021]

Landscape of Quantifier Strategies in cvc5



Theory Solvers supported in cvc5

- Support for many theories
  - Arithmetic, Bit-vectors, Arrays, Datatypes, Floating-Points, Strings
  - **Extended:** Sets, Sequences, Multisets, Finite Fields

- The use of theories can avoid (some) use of quantified formulas, see:
  - (Co)datatypes **[Reynolds et al CADE 2015]**
  - Relations **[Meng et al CADE 2017]**
  - Sequences **[Shing et al IJCAR 2022]**

  $\Rightarrow$ If you have a new problem domain, we can add custom support for it

cvc5: Interfaces for When Things go *Right*

i.e. when the solver says "sat" or "unsat"

- `get-model`
  - *What is the counterexample to the theorem?*
    - Can be refined to only include relevant assignments `get-model-core`
- `get-unsat-core`
  - *What are the necessary assertions for proving this theorem?*
    - Can be minimized via option `--minimal-unsat-core`
    - Finer-grained versions `get-instantiations`
- `get-proof`
  - *What is the precise reasoning for proving the theorem?*

DEMO

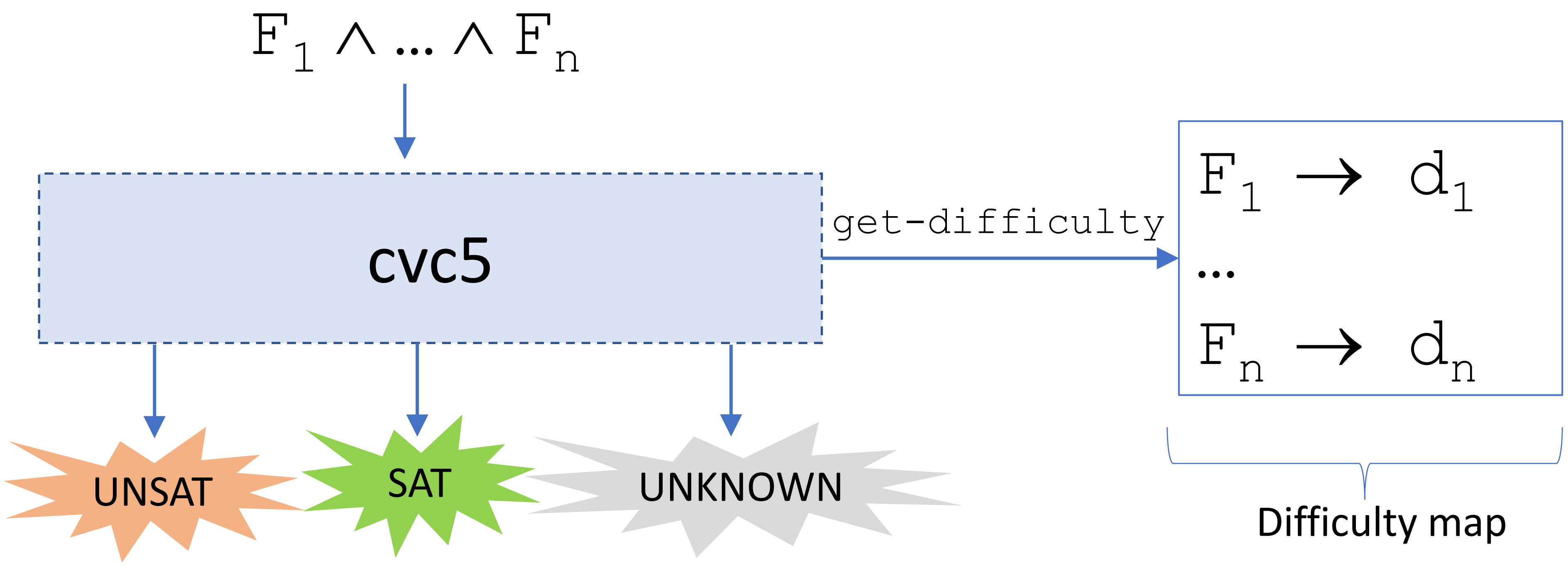
cvc5: Interfaces for When Things go *Wrong*

i.e. when the solver says “unknown” or times out

- `get-model`
  - *What is a candidate counterexample to this theorem?*
    - Available even when the solver times out or gives up
- `get-difficulty`
  - *Which assertions where the reason why this problem was hard?*
- `get-timeout-core`
  - *Which assertions suffice to make the solver time out again?*
- `get-learned-lits`
  - *What immediate formulas were learned during solving?*
- External tools for delta-debugging e.g. `ddSmt` **[Kremer et al 2020]**

Difficulty Estimation

- When cvc5 can't solve an input, can we estimate *why* it was difficult?



The larger d_i, the harder F_i was to solve for

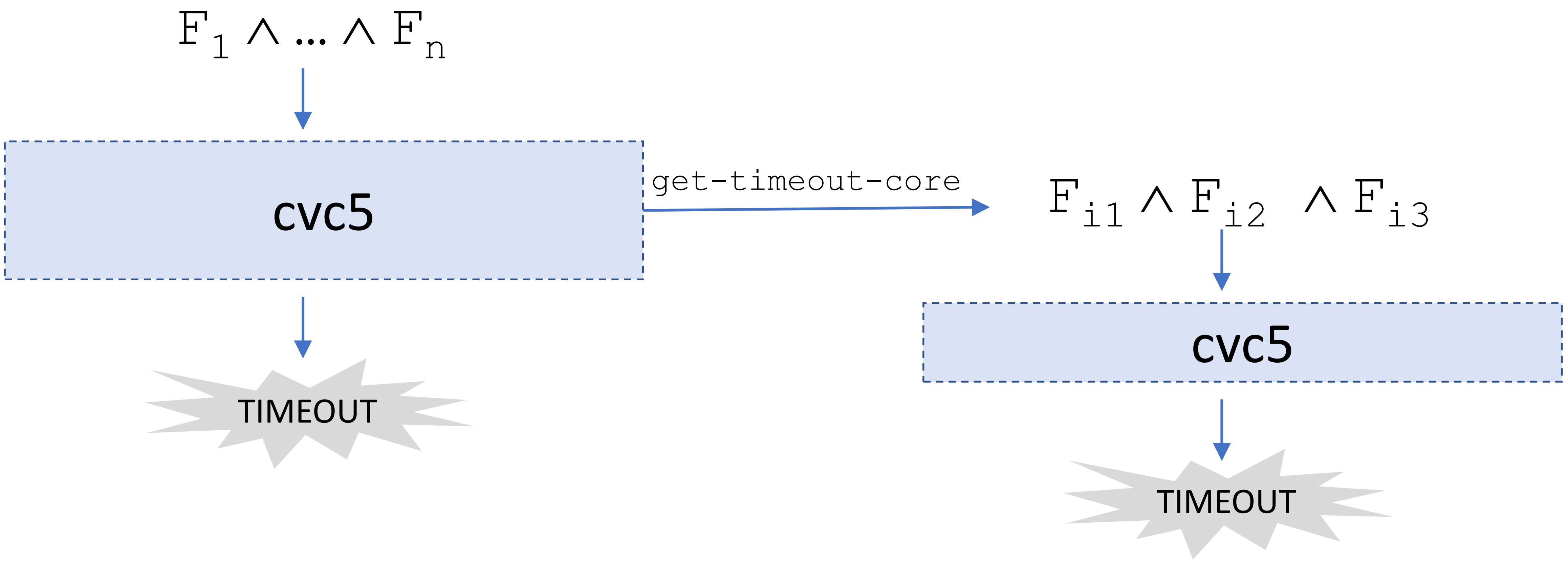
Difficulty Estimation

- Given input $F_1 \wedge \ldots \wedge F_n$
  - Model-based:
    - When a candidate model M is constructed
      - Increment difficulty measure for each F_j that M does not satisfy
  - Conflict-based:
    - When a conflict clause ($l_1 \vee \ldots \vee l_n$) is raised
      - For each literal l_i, increment difficulty measure for the F_j s.t. $F_j \models \neg l_i$

DEMO

Timeout Cores

- Given a timeout, can we construct a smaller problem cvc5 also cannot solve?



Timeout Cores

- To compute a timeout core for $F=\{F_1, \ldots, F_n\}$:
  - Maintain an (initially empty) set of models M
  - Maintain an (initially empty) set of formulas $C \subseteq F$ such that
    - Each model in M does *not* satisfy at least one formula in C
  - Repeat:
    - If C is unsat
      - Report that F is unsat, C is an unsat core of F
    - If C makes the solver timeout
      - Report that C is a timeout core of F
    - If C is sat with model m
      - If m satisfies F
        - Report that F is sat
      - Else, add m to M, add some F_i to C s.t. m does not satisfy F_i, refine C

DEMO

- SMT solver cvc5 is
  - Efficient tool widely used in applications
  - Handles many problem domains
  - Many interfaces for when things go right (or wrong)

- Questions?