A Default Perspective on OWL: How to Keep Your Knowledge Consistent

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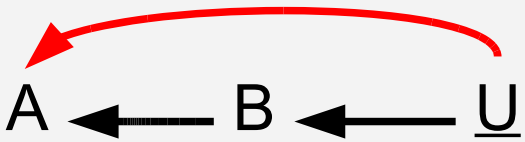
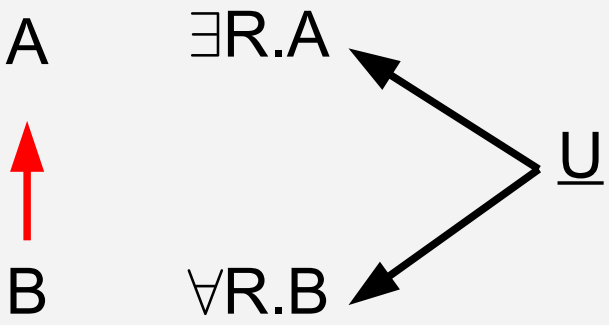
Conflicts all Over: Unsatisfiable Concepts

explicit

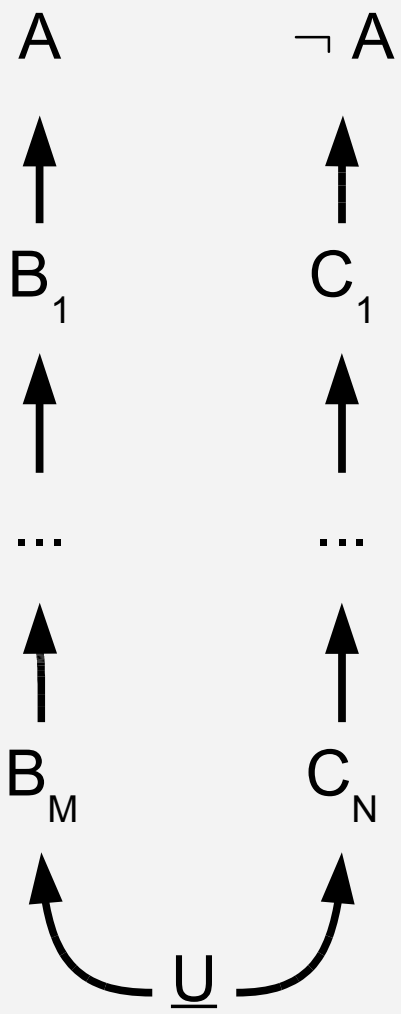


implicit



- Conflicts cause inconsistencies!
- Conflicts indicate modelling errors!
- Conflicts are Evil!

General Conflict Pattern



CONFLICTS HAVE TRACES

- Every conflict has **two traces**
  - Trace1: $O \models U \sqsubseteq \neg A$
  - Trace2: $O \models U \sqsubseteq B$
  - Constraint: $O \models A \sqcap B \sqsubseteq \bot$
- Break traces' inferences
  - Remove axioms
  - Remove inferences

Resolve General Conflict Pattern

Solution1: Remove Axioms

- Non-Monotonic Operation
- No Change in Logics
- Monotone Logics
- Removes Inferences
- Removes Axioms

Solution2: Remove Inferences

- Non-Monotonic Operation
- Change Logics
- Non-Monotone Logics
- Removes Inferences
- Preserves Axioms

Solution1: Remove Axioms

- Identify potentially **bad axioms**
- Remove as many axioms as necessary
- **Keep formalism** for reasoning

Finding Minimal Unsat-Preserving Sets

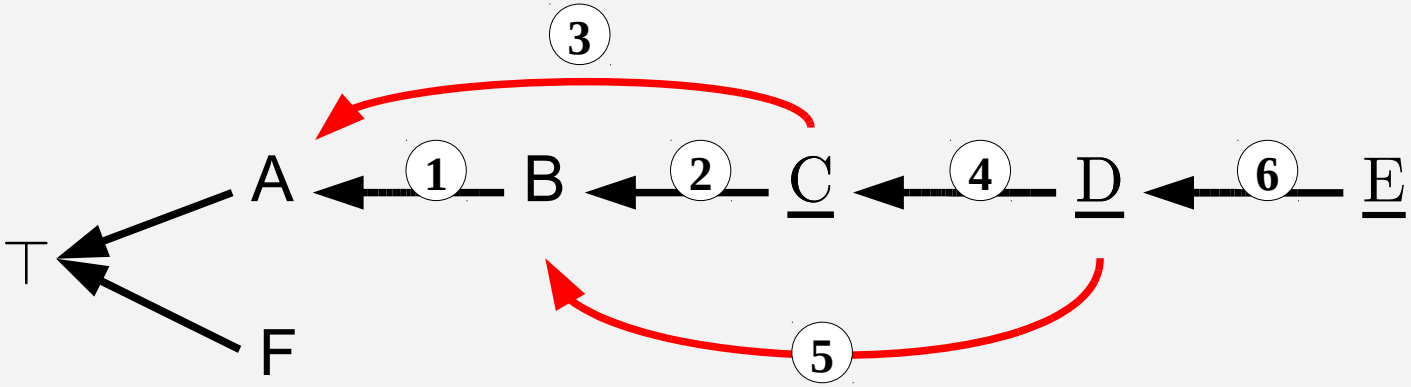
- Justification J_η for entailment $\mathcal{T} \models \eta$

  $J_\eta \subseteq \mathcal{T}$ such that

  (1) $J_\eta \models \eta$ and (2) $J_\eta \subset J'_\eta$ for any $J'_\eta \models \eta$

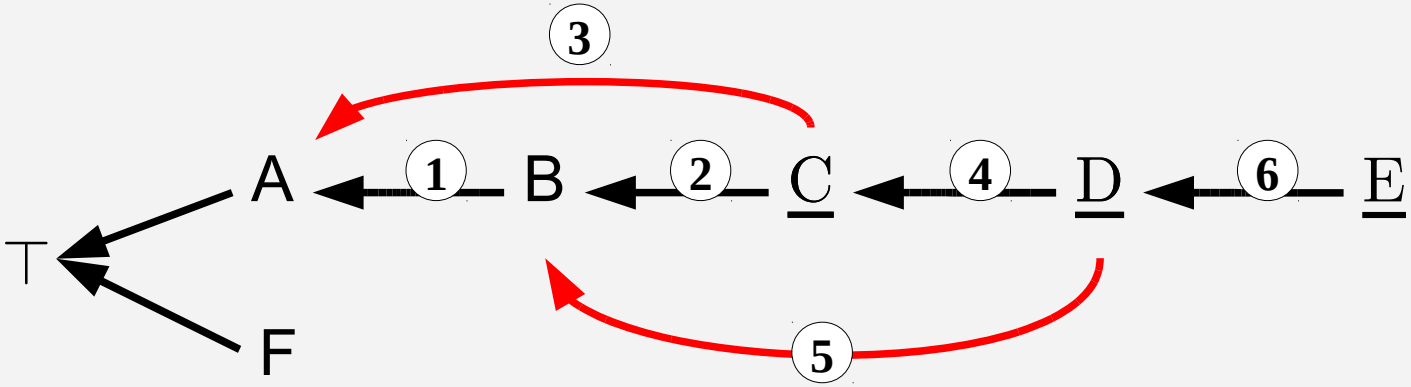
- **Minimal set of axioms** such that entailment still holds

Example



1 2 3 4 5 6

Example for $\mathbf{C} \sqsubseteq \bot$

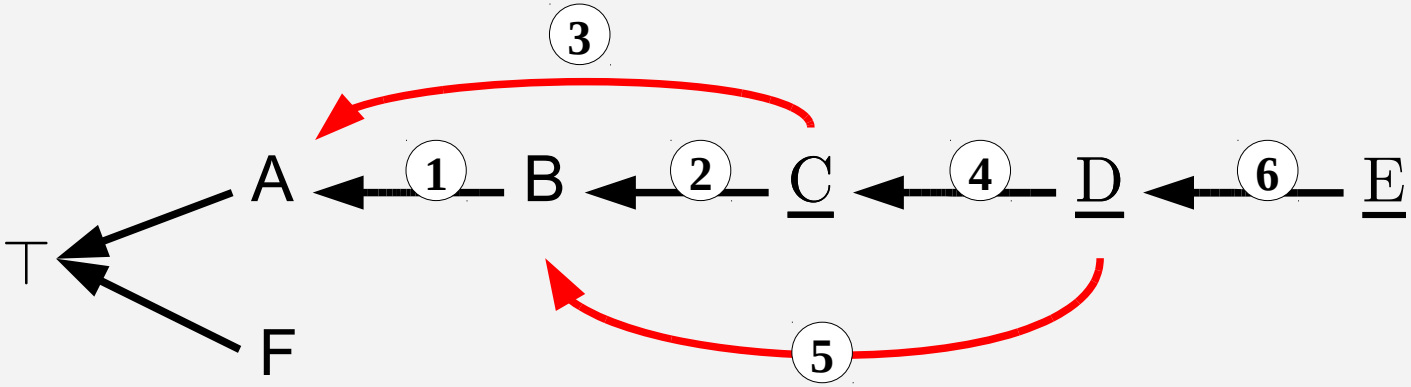


$$\mathrm{J} = \textcircled{1}\ \textcircled{2}\ \textcircled{3}\ \textcircled{4}\ \textcircled{5}\ \textcircled{6}$$

Entails? ✗ $\mathrm{J} \not\models \mathrm{C} \sqsubseteq \bot$

Minimal?

Example for $\mathbf{C} \sqsubseteq \bot$



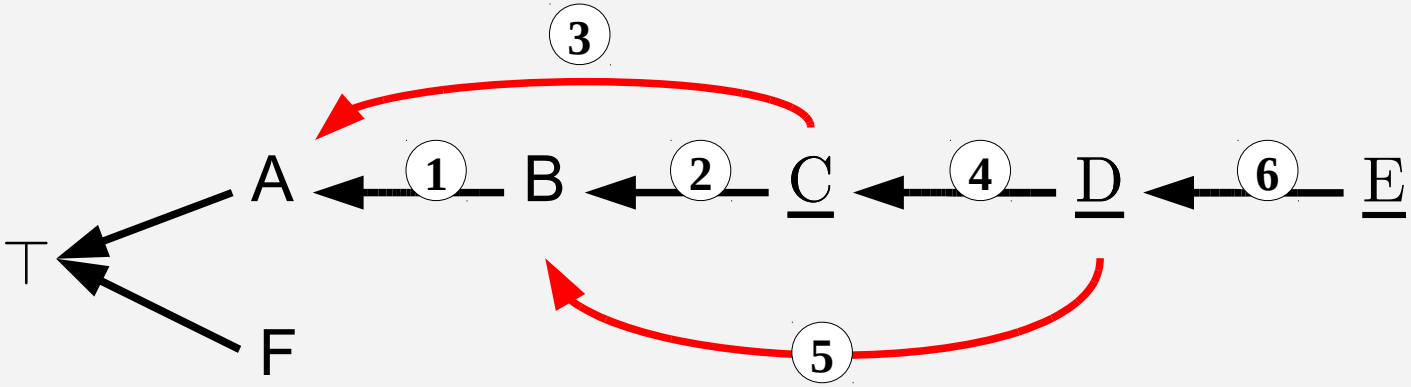
$$\mathbf{J} = \textcircled{1}\ \textcircled{2}\ \textcircled{3}\ \textcircled{4}\ \textcircled{5}\ \textcircled{6}$$

Entails? ✔ $\mathbf{J} \models \mathbf{C} \sqsubseteq \bot$

Minimal? ✘ $\mathbf{J}$ is not minimal!

remove ④

Example for $\mathbf{C} \sqsubseteq \bot$

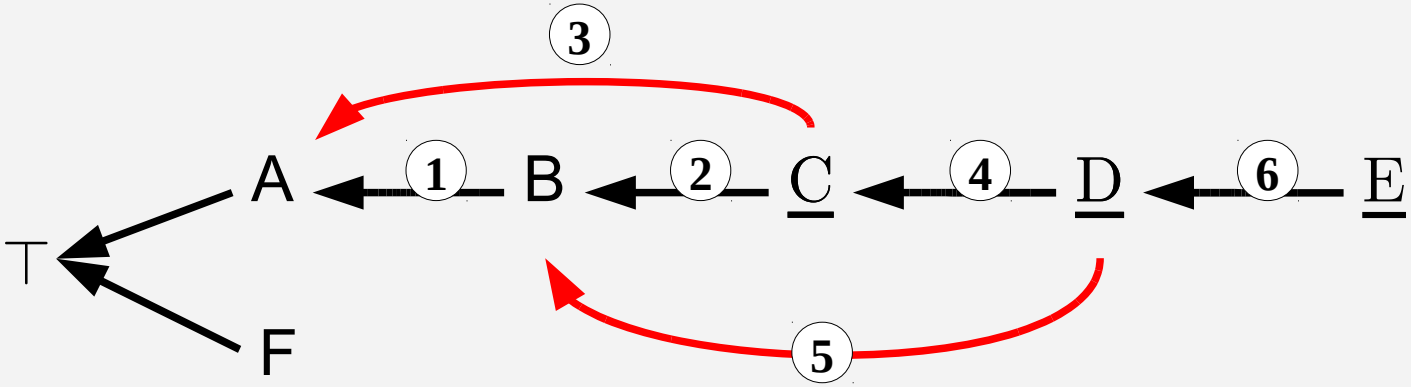


$$\mathbf{J} = \textcircled{1}\ \textcircled{2}\ \textcircled{3}\ \textcircled{4}\ \textcircled{5}\ \textcircled{6}$$

Entails? ✔ $\mathbf{J} \models \mathbf{C} \sqsubseteq \bot$

Minimal? ✔ $\mathbf{J}$ is minimal!

Example for D $\sqsubseteq \bot$

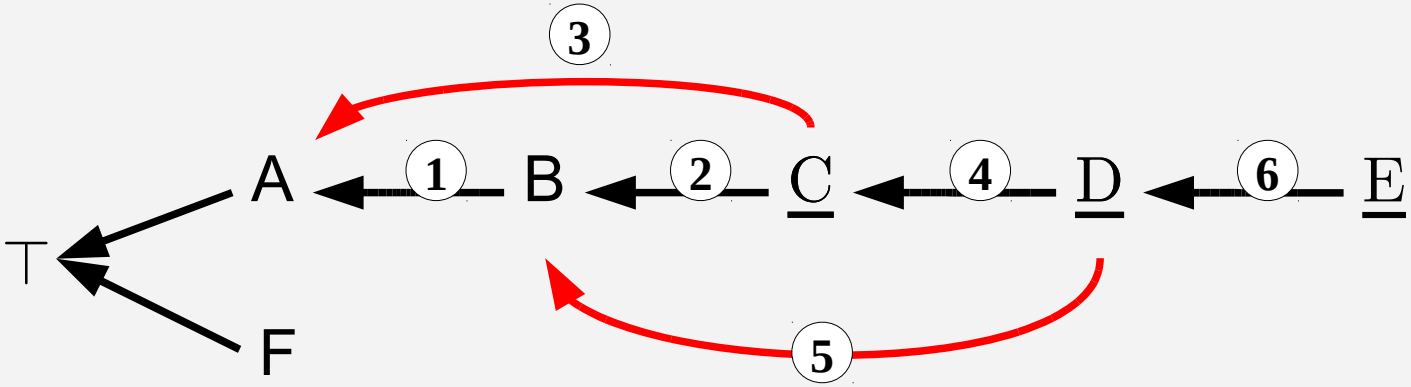


$$\mathcal{J} = \{1, 2, 3, 4, 5, 6\}$$

Entails? ✔ $\mathcal{J} \models D \sqsubseteq \bot$

Minimal? ✔ $\mathcal{J}$ is minimal!

Example for D $\sqsubseteq \bot$

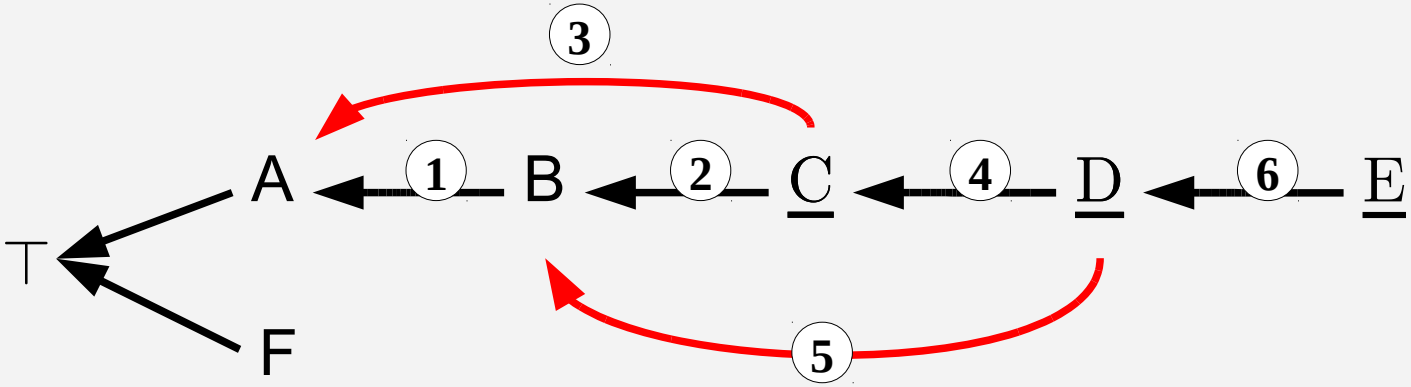


$$J = \{1, 2, 3, 4, 5, 6\}$$

Entails? ✗ $J \not\models D \sqsubseteq \bot$

Minimal?

Example for D $\sqsubseteq \bot$



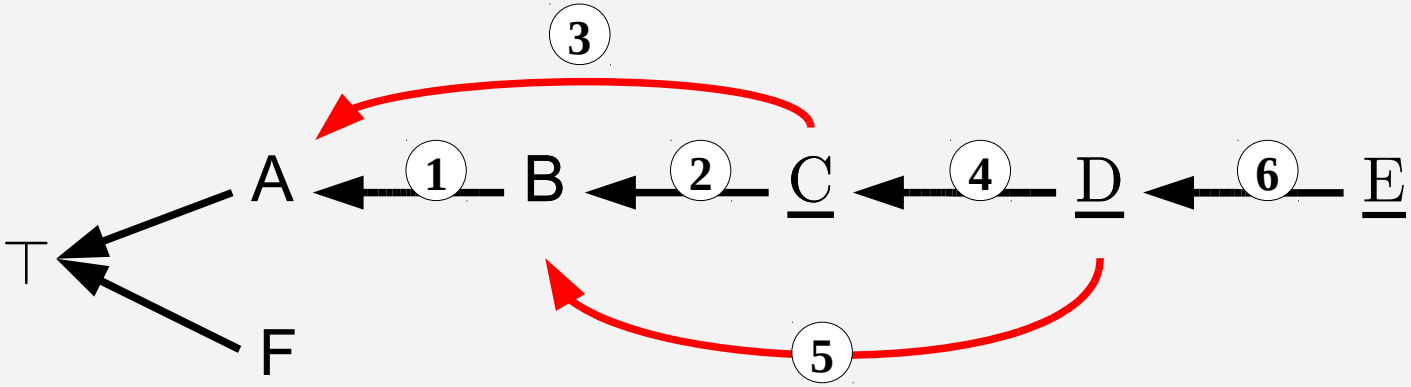
$$\mathcal{J} = \{1, 2, 3, 4, 5, 6\}$$

Entails? ✔ $\mathcal{J} \models D \sqsubseteq \bot$

Minimal? ✘ $\mathcal{J}$ is not minimal!

remove 1

Example for D $\sqsubseteq \bot$

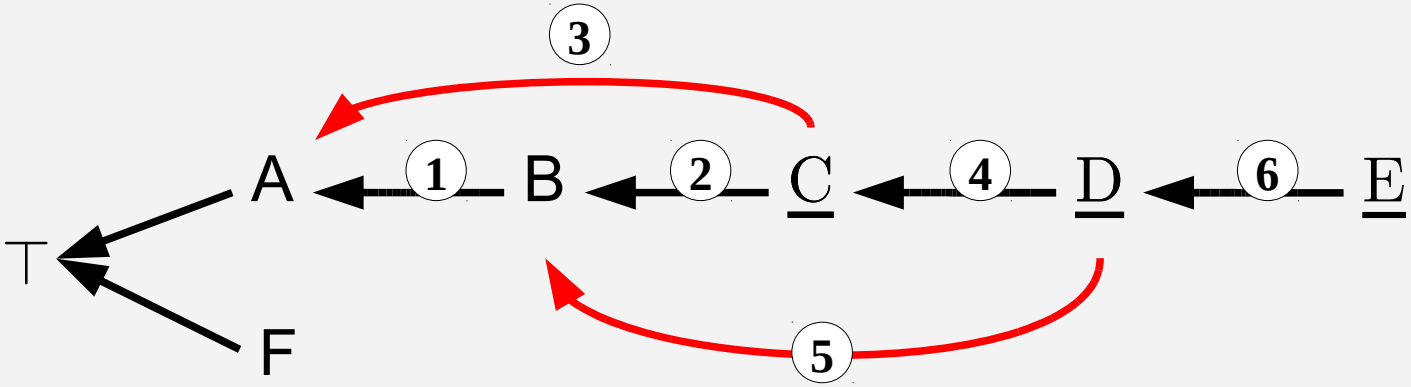


$$\mathcal{J} = \{1, 2, 3, 4, 5, 6\}$$

Entails? ✔ $\mathcal{J} \models D \sqsubseteq \bot$

Minimal? ✔ $\mathcal{J}$ is minimal!

Example for E $\sqsubseteq \bot$



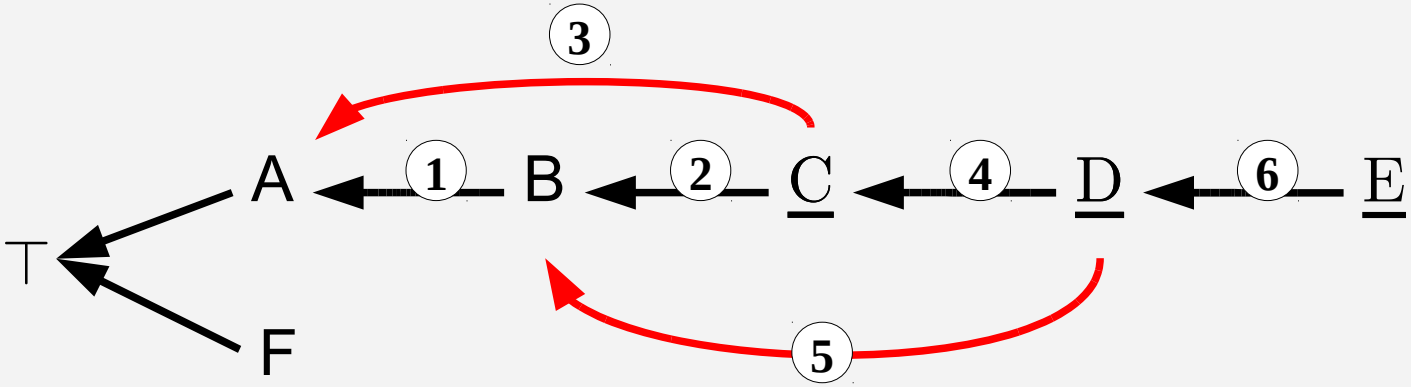
$J =$ (1) (2) (3) (4) (5) (6)

Entails? ✔ $J \models E \sqsubseteq \bot$

Minimal? ✘ J is not minimal!

remove either (5) or (1) (3)

Example for E $\sqsubseteq \bot$

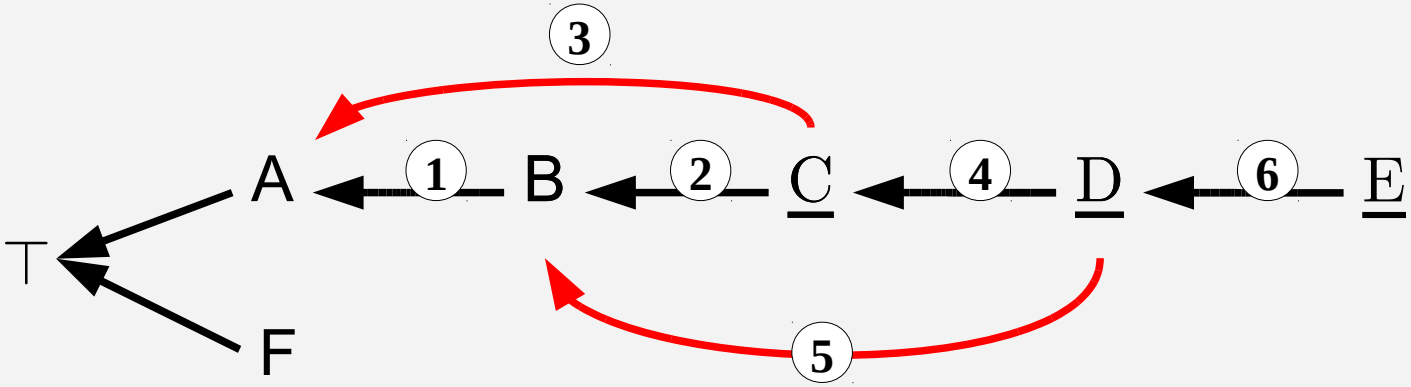


$$\mathrm{J} = \textcircled{1}\ \textcircled{2}\ \textcircled{3}\ \textcircled{4}\ \textcircled{5}\ \textcircled{6}$$

Entails? ✔ $\mathrm{J} \models \mathrm{E} \sqsubseteq \bot$

Minimal? ✔ J is minimal!

Example for E $\sqsubseteq \bot$

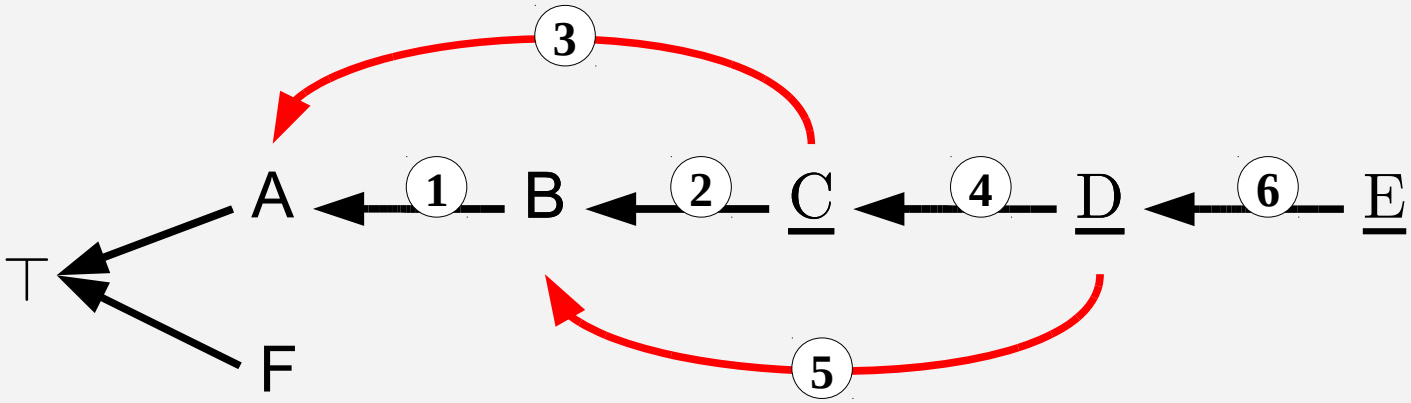


$$\mathcal{J} = \{1, 2, 3, 4, 5, 6\}$$

Entails? ✔ $\mathcal{J} \models E \sqsubseteq \bot$

Minimal? ✔ $\mathcal{J}$ is minimal!

Justifications for Example:



$J^1_{C \sqsubseteq \bot} = \{1, 2, 3\}$

$J^1_{D \sqsubseteq \bot} = \{1, 2, 3, 4\}$ $\quad J^2_{D \sqsubseteq \bot} = \{2, 4, 5\}$

$J^1_{E \sqsubseteq \bot} = \{1, 2, 3, 4, 6\}$ $\quad J^2_{E \sqsubseteq \bot} = \{2, 4, 5, 6\}$

Root Justifications

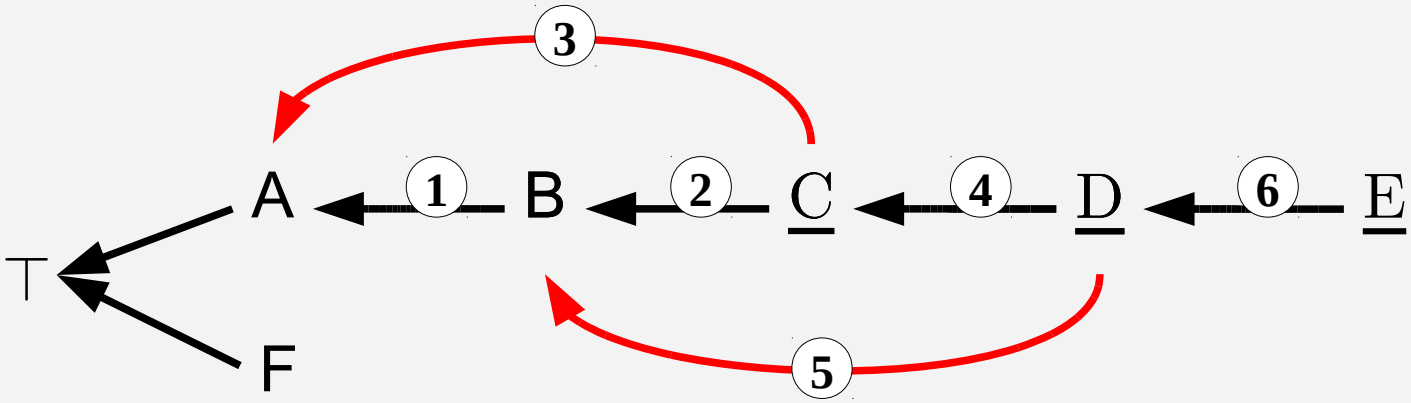
ROOT CAUSES
MINIMAL REPAIR

- Root Justification:
  Justification that does not depend on another justification

- Breaking root justification **breaks dependent justifications**
  - If J_η is not valid anymore,
  - then all J'_φ with $J'_\varphi \supset J_\eta$ are also not valid anymore

Root justifications allow Minimal Repair!

Justifications for Example:

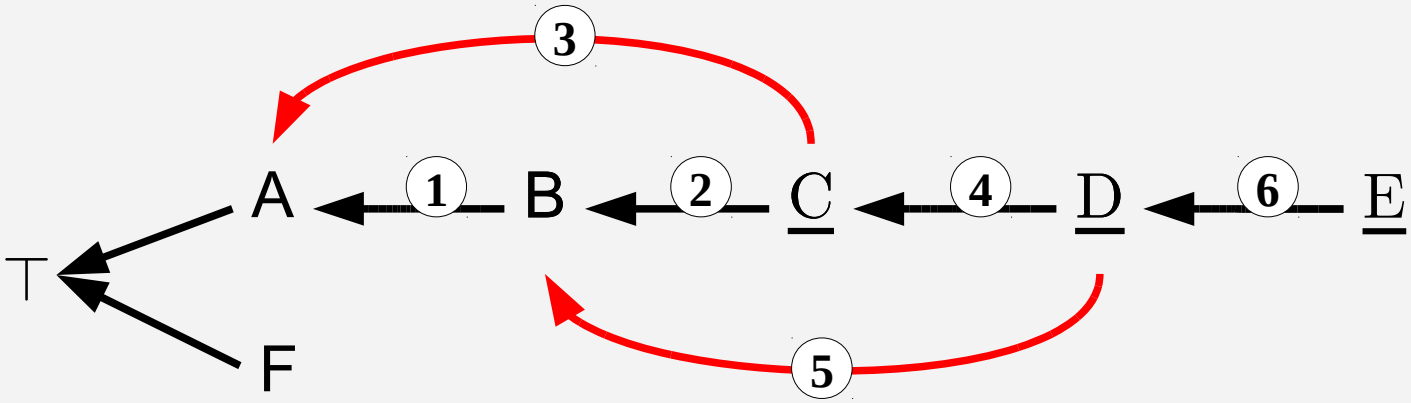


$$J^1_{C \sqsubseteq \bot} = \{1, 2, 3\}$$

$$J^1_{D \sqsubseteq \bot} = \{1, 2, 3, 4\} \qquad J^2_{D \sqsubseteq \bot} = \{2, 4, 5\}$$

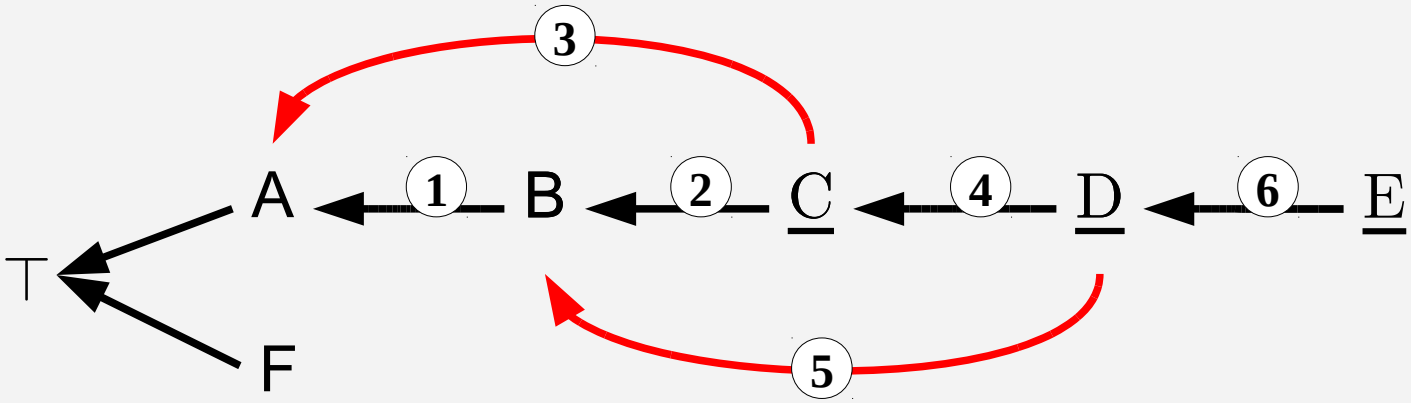
$$J^1_{E \sqsubseteq \bot} = \{1, 2, 3, 4, 6\} \qquad J^2_{E \sqsubseteq \bot} = \{2, 4, 5, 6\}$$

Root Justifications for Example:



$J^1_{C \sqsubseteq \bot} = \{1, 2, 3\}$ $J^2_{D \sqsubseteq \bot} = \{2, 4, 5\}$

Solution 1: Remove One Axiom From Each Root Justification



$J^1_{C \sqsubseteq \bot} = \{1, 2, 3\}$ $J^2_{D \sqsubseteq \bot} = \{2, 4, 5\}$

- Here: Minimal repair possible by removing Axiom 2
- In General: Combinatorial and Optimization Problem

Computing Justifications

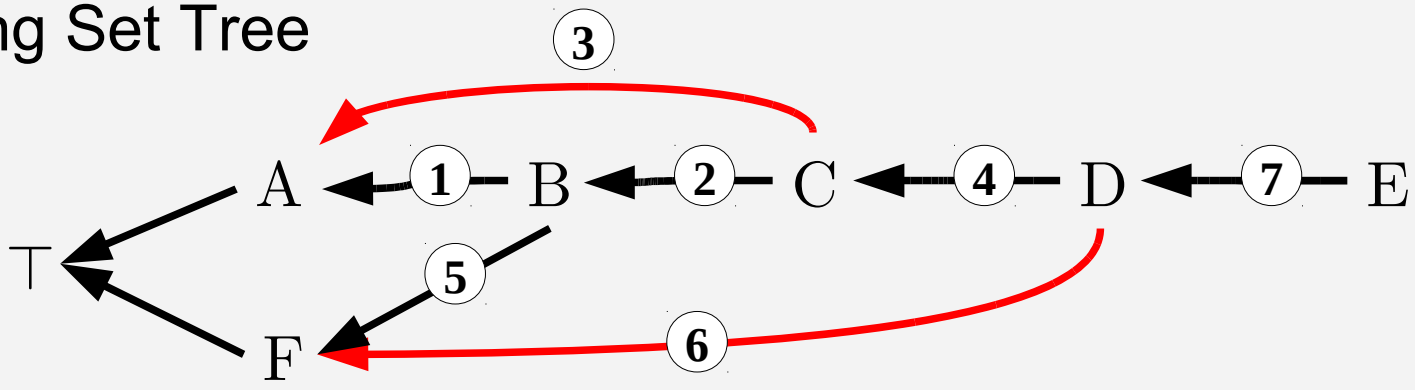
- Blackbox Approach (Brute-Force):

  TBox T, unsat concept U such that T models U bot

  1) Start with empty TBox T'
  2) As long as T' not models U bot, add axioms from T
  3) As long as T' models U bot remove axioms from T'

Computing Justifications: HST

- Hitting Set Tree



Summary Solution1: Remove Axioms

- For each unsatisfiable concept:
  - Compute **All root justifications** $\mathrm{J}^{\mathrm{n}}_{\mathrm{root}}$
  - Remove **one axiom from each** $\mathrm{J}^{\mathrm{n}}_{\mathrm{root}}$
- Combinatorial and Optimization Problem:
  - What combination of axioms to remove?

End of part 1...

Take a deep breath ...

Solution 2: Remove Inferences

- Breaks monotonicity:

  Adapted reasoning formalism required

- Central Question:

  How to choose **valid inferences**?

- Solution:

  Incorporate **context information**!

Adapted Reasoning Formalisms

- Paraconsistent Logics (Multi-valued logics)
  - More than one state of the world
  - **Different reasoning** as DL
- Default Logics (Modal Logics)
  - **Preference model** on axioms and inferences
  - Rely upon **structure of TBox** only
  - **Similar reasoning** as DL

Default Logics

- Models Exceptional Knowledge:
  - DescriptionLogics: B $\sqsubseteq$ A: *In all cases*, if B, then A
  - Default Logics: (B|A): *Generally*, if A then B
- Preference Relation:
  - Place axioms not involved in contradiction in **TBox**
  - Place contradicting axioms into **different partitions**
  - **Prefer axioms** in **more specific** over axioms in more general partitions

Computing Partitions: Naive Approach

- Pn is the set of all axioms

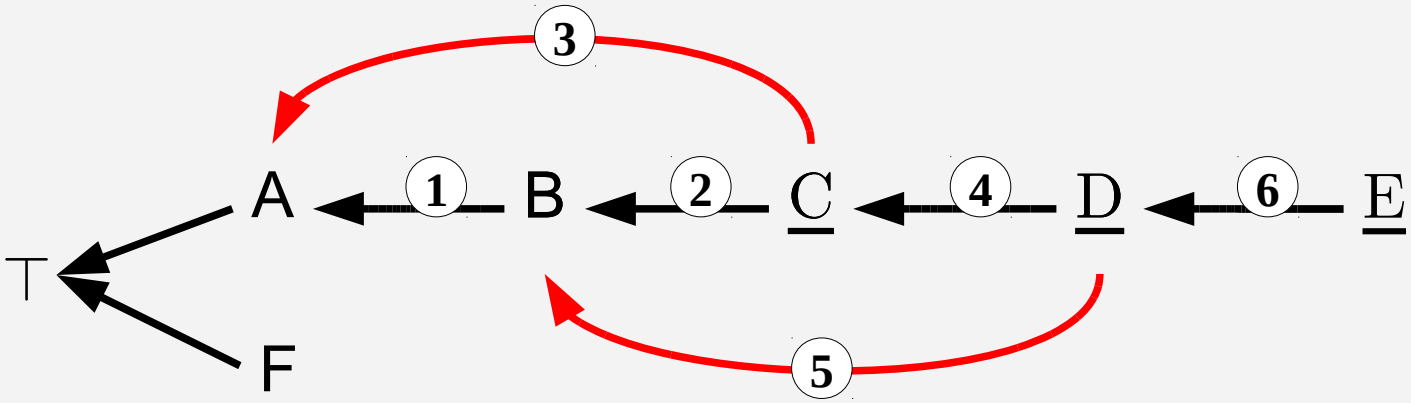
  for which all **classes in its signature are satisfiable**

  w.r.t. the TBox together with the remaining axioms.

- Default Knowledge Base is consistent,

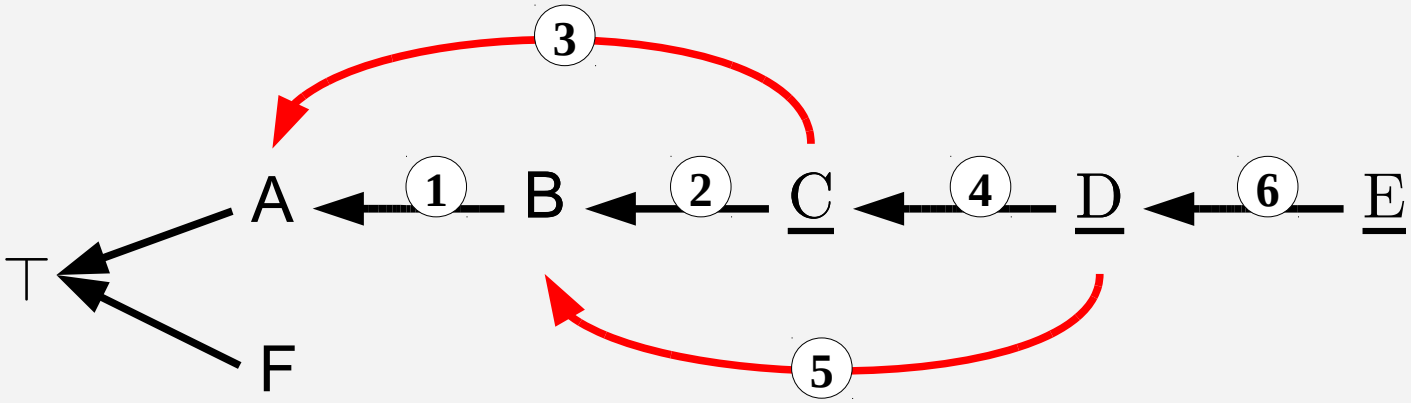
  if set of axioms can be partitioned

Remember: Root Justifications for Example



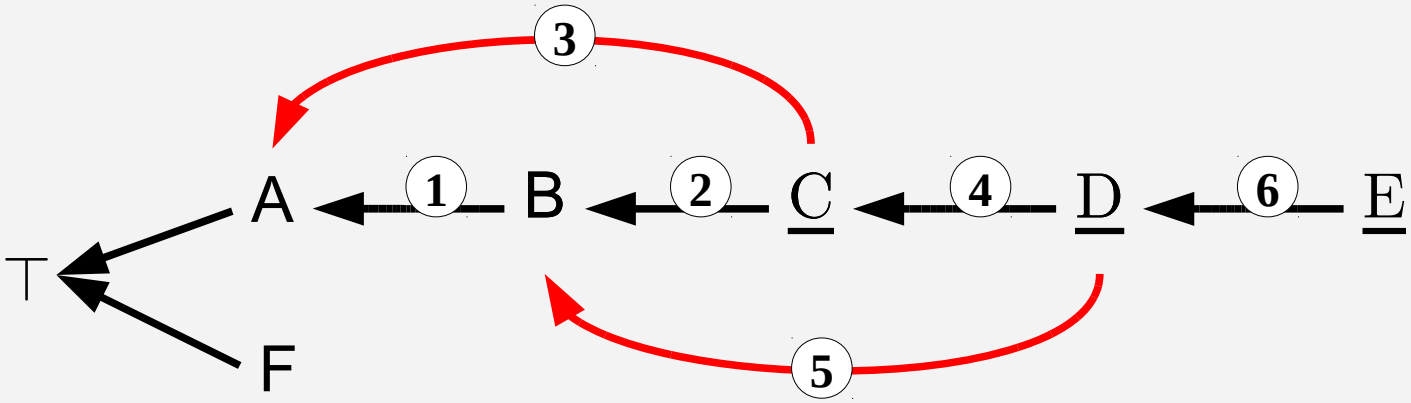
$J^1_{C \sqsubseteq \bot} = \{1, 2, 3\}$ $J^2_{D \sqsubseteq \bot} = \{2, 4, 5\}$

Naive Partition Approach for Example



T = 6 Candidates = 1 2 3 4 5

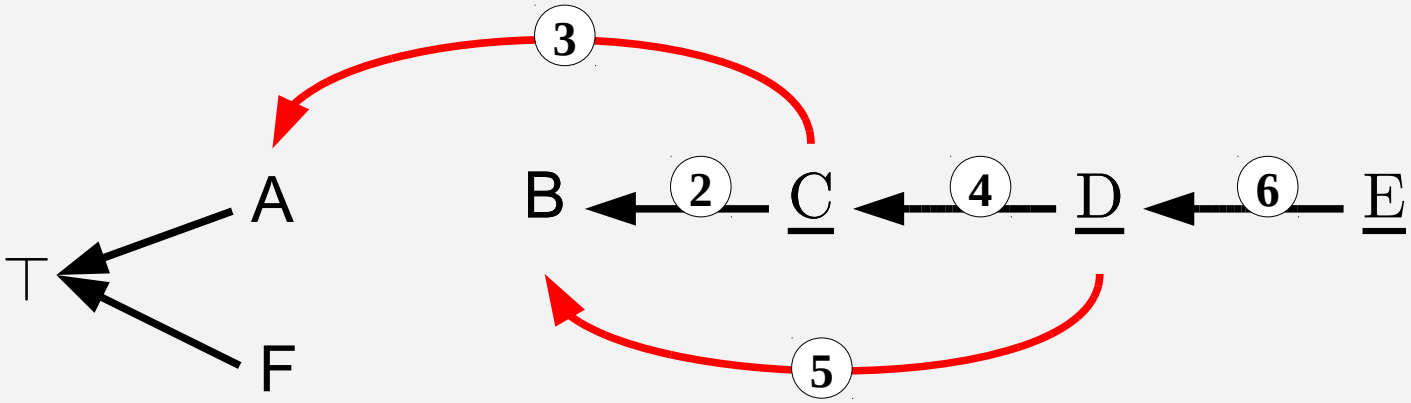
Computing First Partition



T = 6 Candidates = 1 2 3 4 5

P_0 = 1

Computing Next Partition

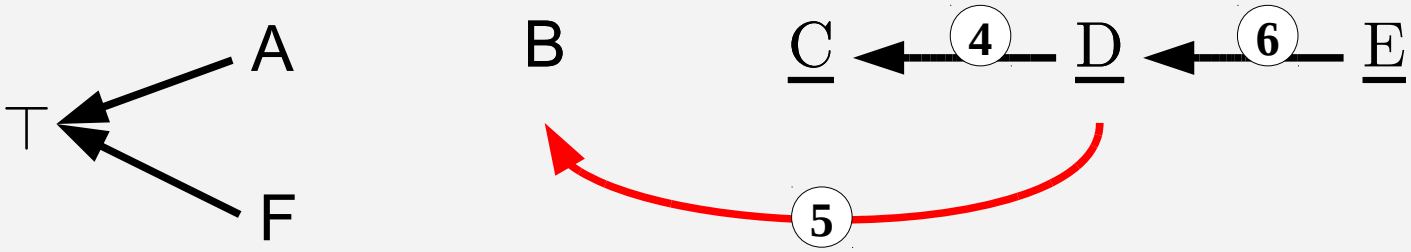


T = 6 Candidates = 2 3 4 5

P_0 = 1

P_1 = 2 3

Computing Next Next Partition



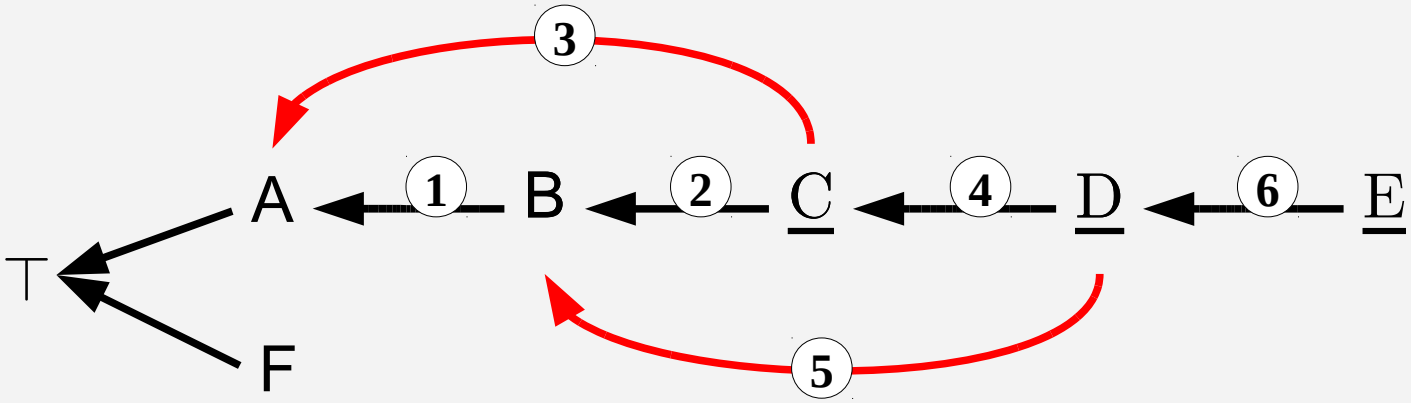
T = 6 Candidates = 4 5

P_0 = 1

P_1 = 2 3

P_2 = 4 5

Naive Partition Approach for Example



T = 6 Candidates = 1 2 3 4 5

P_0 = 1

P_1 = 2 3

P_2 = 4 5

Summary Solution 2: Remove Inferences

- Change to Default Logics
- Non-monotone
- TBox: Knowledge force to hold
- Partition: Preference relation on axioms
- Consistent, if partition exists

End of part 2...

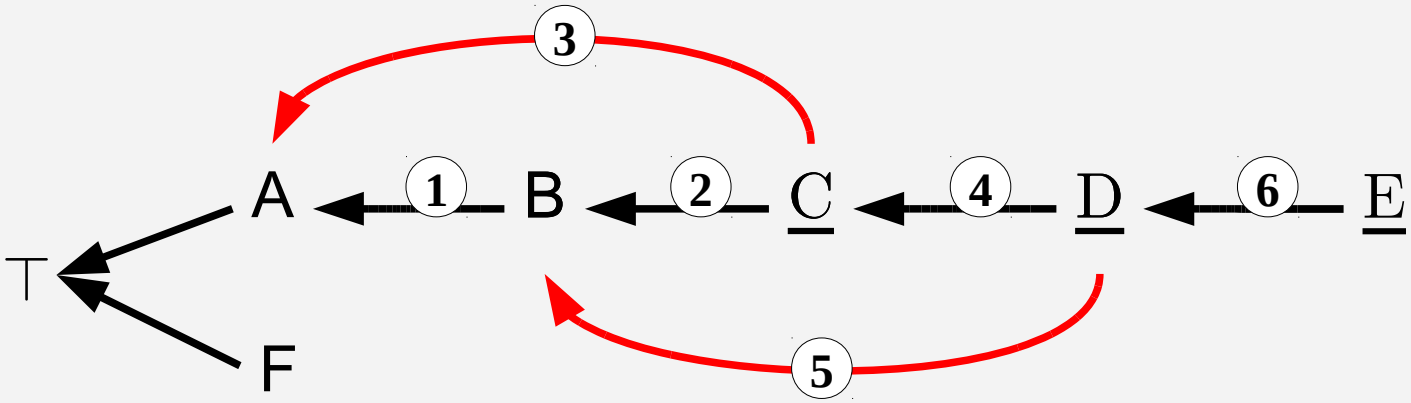
You may sigh...

Take another deep breath ...

Computing Partitions: Theta-Gamma-Splitting

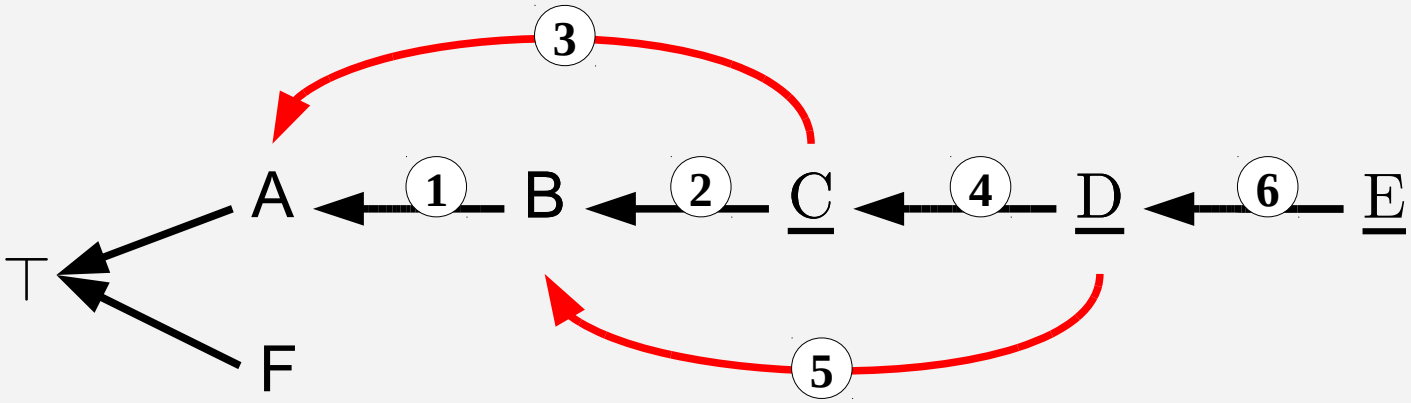
- Naive computation requires additional satisfiability checks!
- Idea: Sat-Checks have already been done while computing justifications
- There must be more information in the justifications!

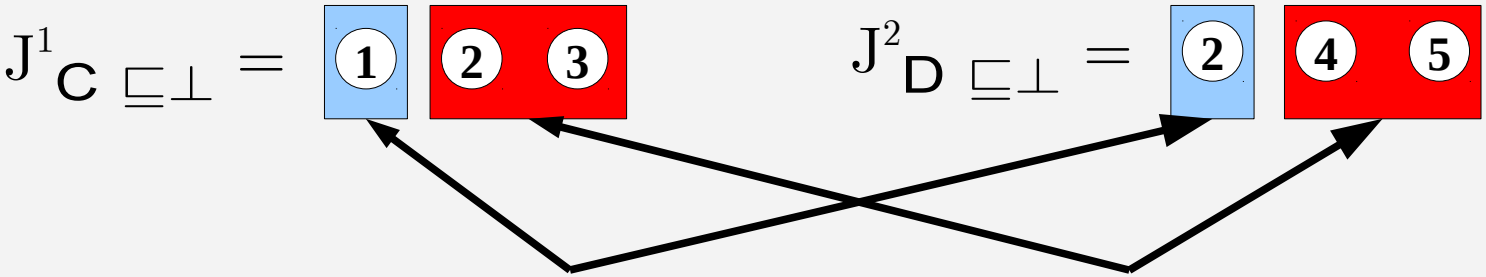
Remember: Root Justifications for Example



$J^1_{C \sqsubseteq \bot} = \{1, 2, 3\}$ $J^2_{D \sqsubseteq \bot} = \{2, 4, 5\}$

Split Root Justifications

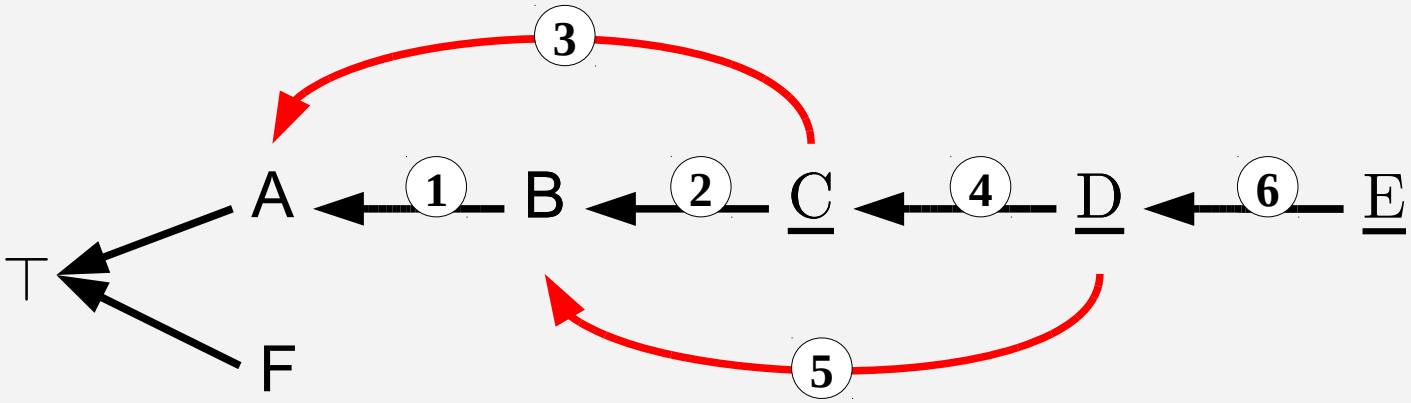




Theta-Set:
unsat concept
not in signature

Gamma-Set:
unsat concept
in signature

Split Root Justifications



$J^1_{C \sqsubseteq \bot} =$ {1} {2 3}

$J^2_{D \sqsubseteq \bot} =$ {2} {4 5}

$P_0 =$ {1}

$P_1 =$ {2} {3}

$P_2 =$ {4} {5}

1)Transform all Theta that are not in Gamma

2)Transform all Gamma for which Theta is empty

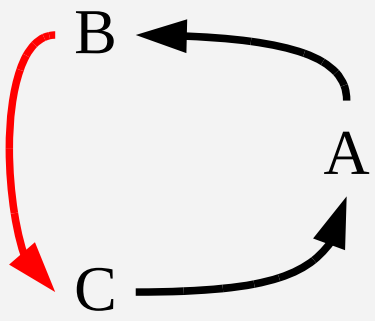
Theta-Gamma Splitting

- Gives **same results** as naive approach!
- Can be further optimized
  - Traces
- Can also be applied to inconsistencies.

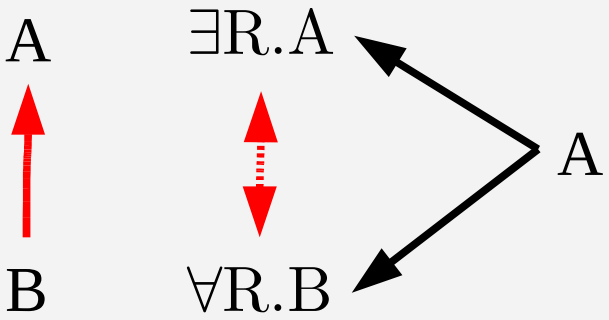
The Fineprint: When is Splitting Consistent?

- No Logical Contradictions

- No Cycles



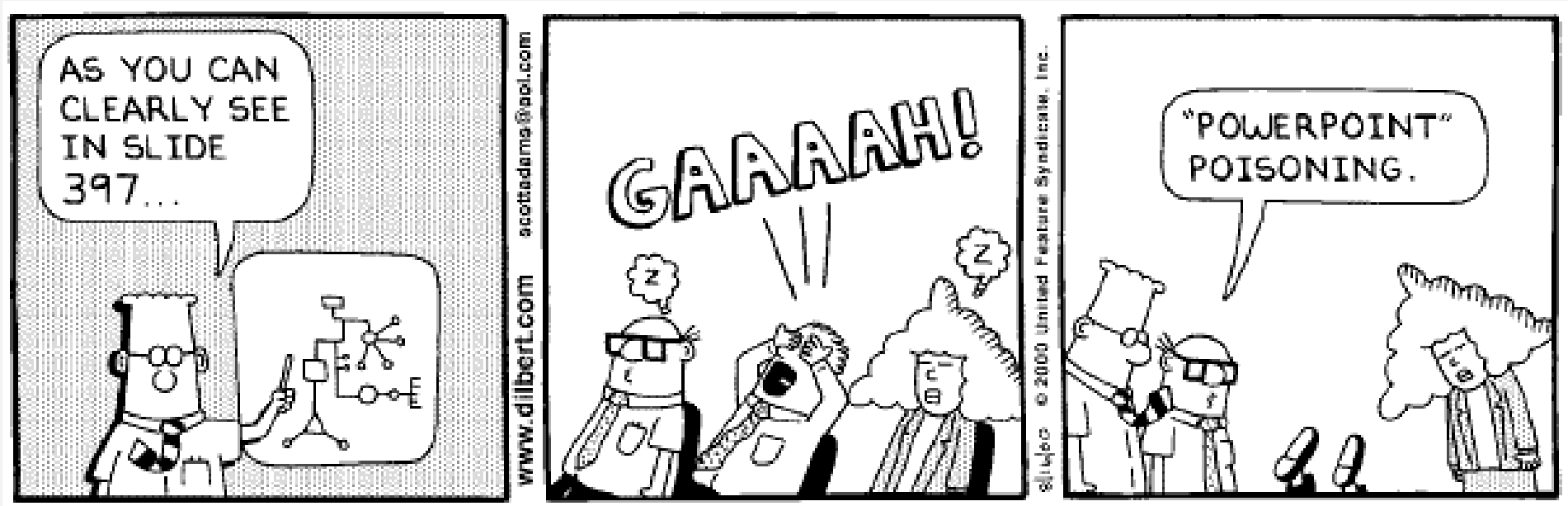
- No Explicit Contradictions



Summary

- For Ontology Repair, break **troublecausing inferences**
- Compute **root justifications** to find root caues.
- Remove **either axioms or inferences**.

Slide 397:
That's it for the moment...



... and **thanks** for your **attention**

... any **feedback** is greatly **appreciated**

References

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