Stream Reasoning with Answer Set Programming

— Preliminary Report —

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Outline

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Motivation

- Answer Set Programming (ASP) integrates
  1. Concise high-level (first-order) specification
  2. Powerful low-level (propositional) reasoning

↪ Two-phase computations

  1. Instantiation (*gringo*)
  2. Search (*clasp*)

- Stream processing concerned with
  1. High-throughput
  2. Continuous data

- How use ASP for knowledge-intense stream reasoning?
  1. Handle emerging/expiring data upon instantiation
  2. Reuse previously learned information upon search

- Knowledge-intense stream reasoning can benefit from
  1. High automation
  2. Computational power

  offered by ASP systems

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- Knowledge-intense stream reasoning can benefit from
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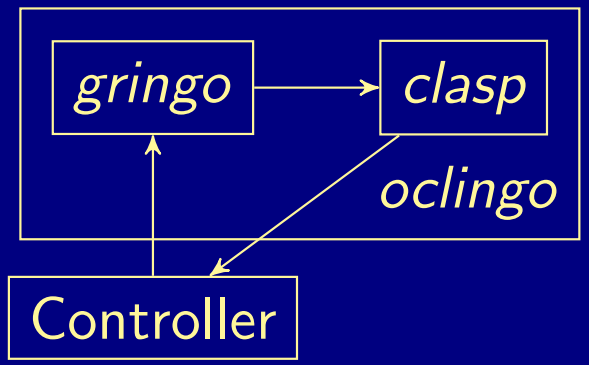
Outline

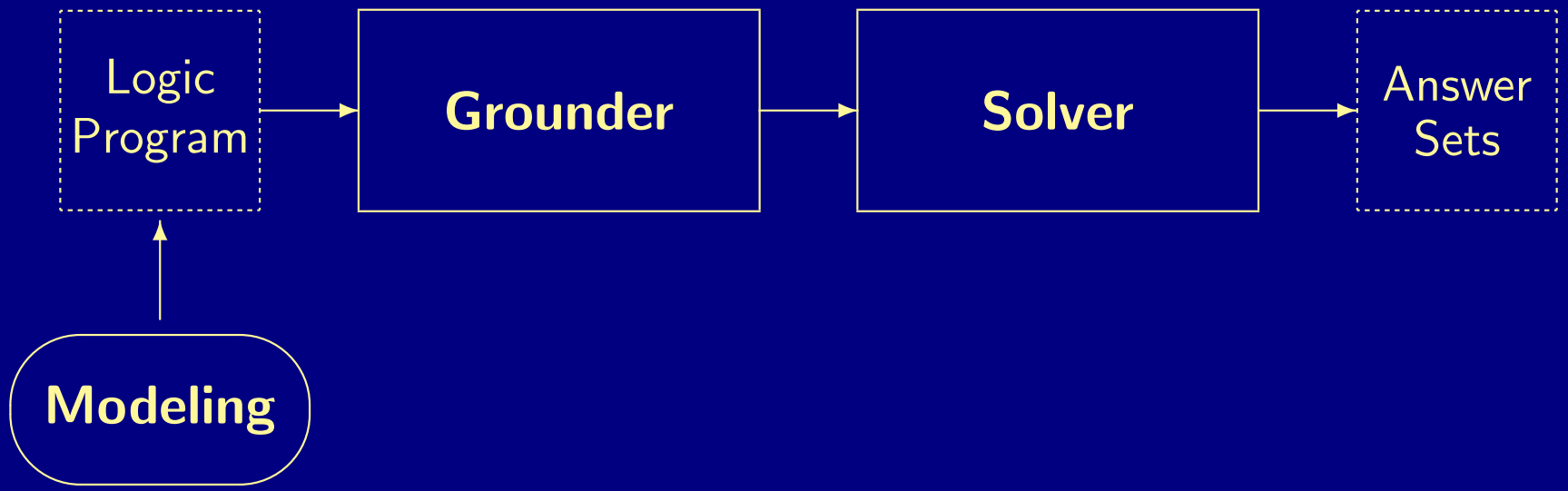
oclingo

- Reactive grounding and solving
- Online solving in dynamic domains, like Robotics

- Basic architecture of *oclingo*:



Reactive ASP Solving Process



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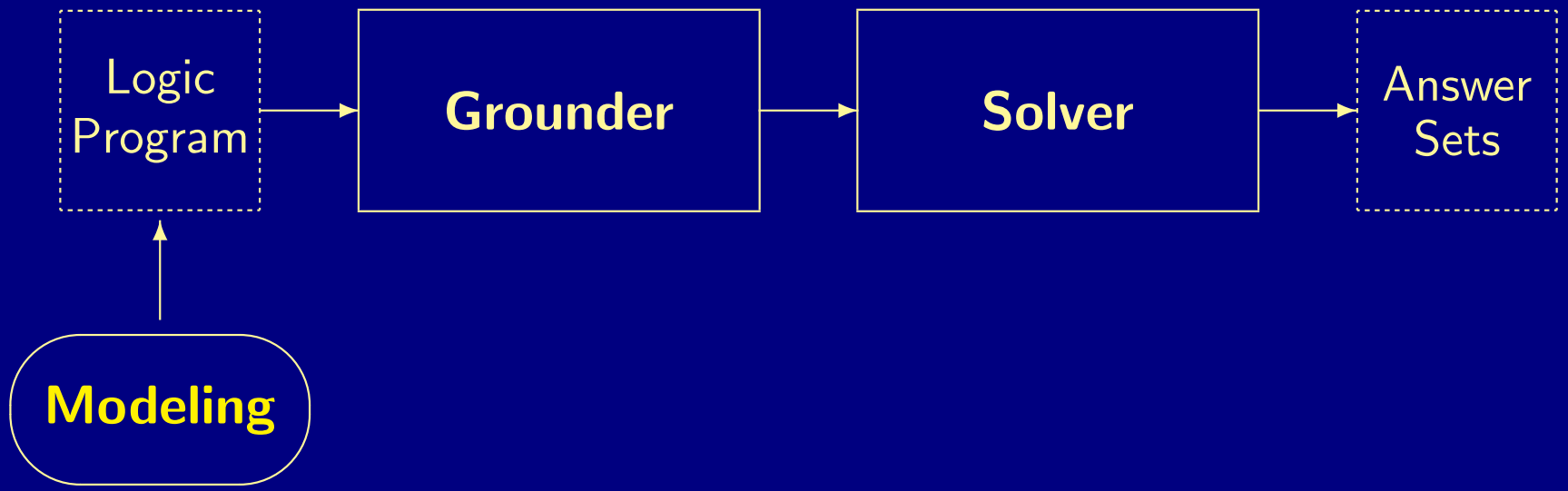

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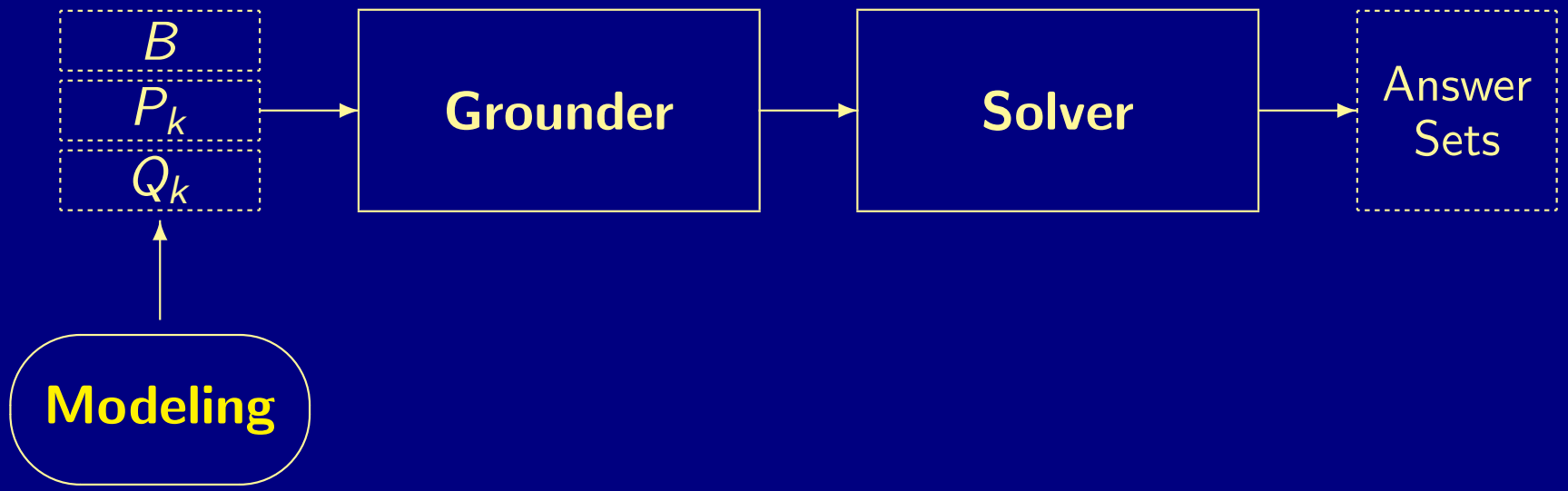

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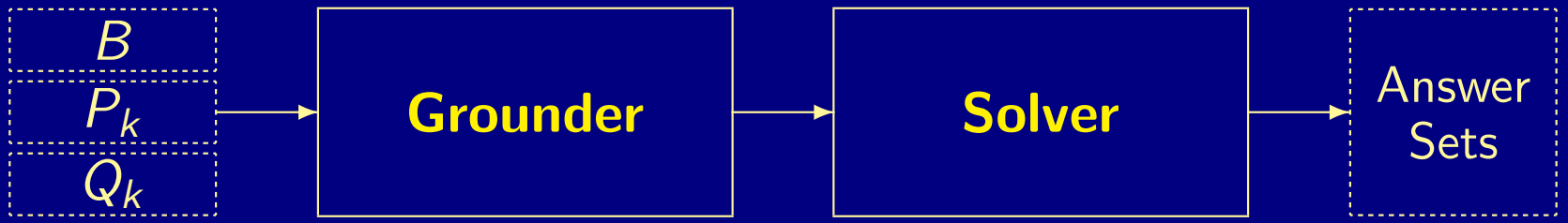

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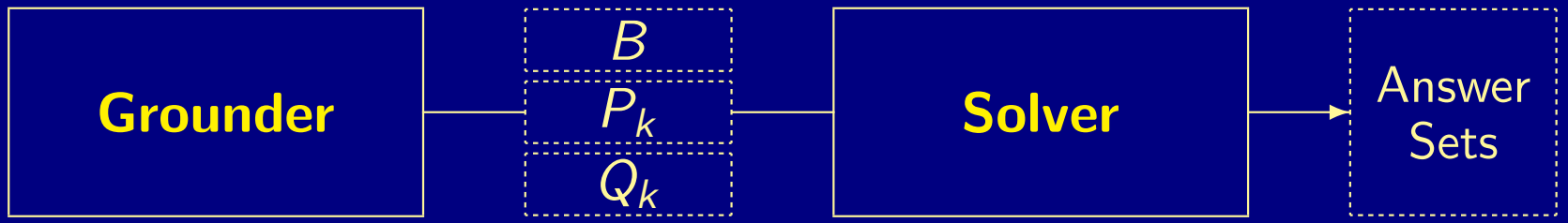

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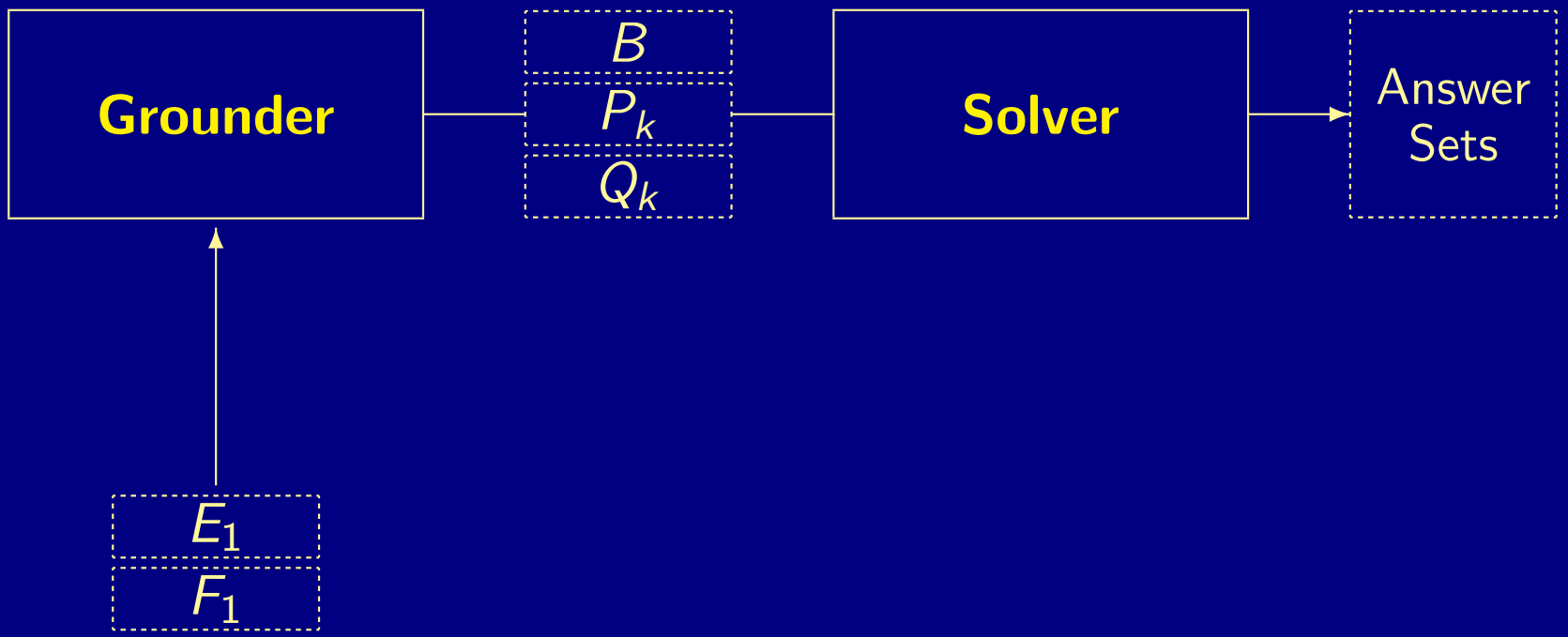

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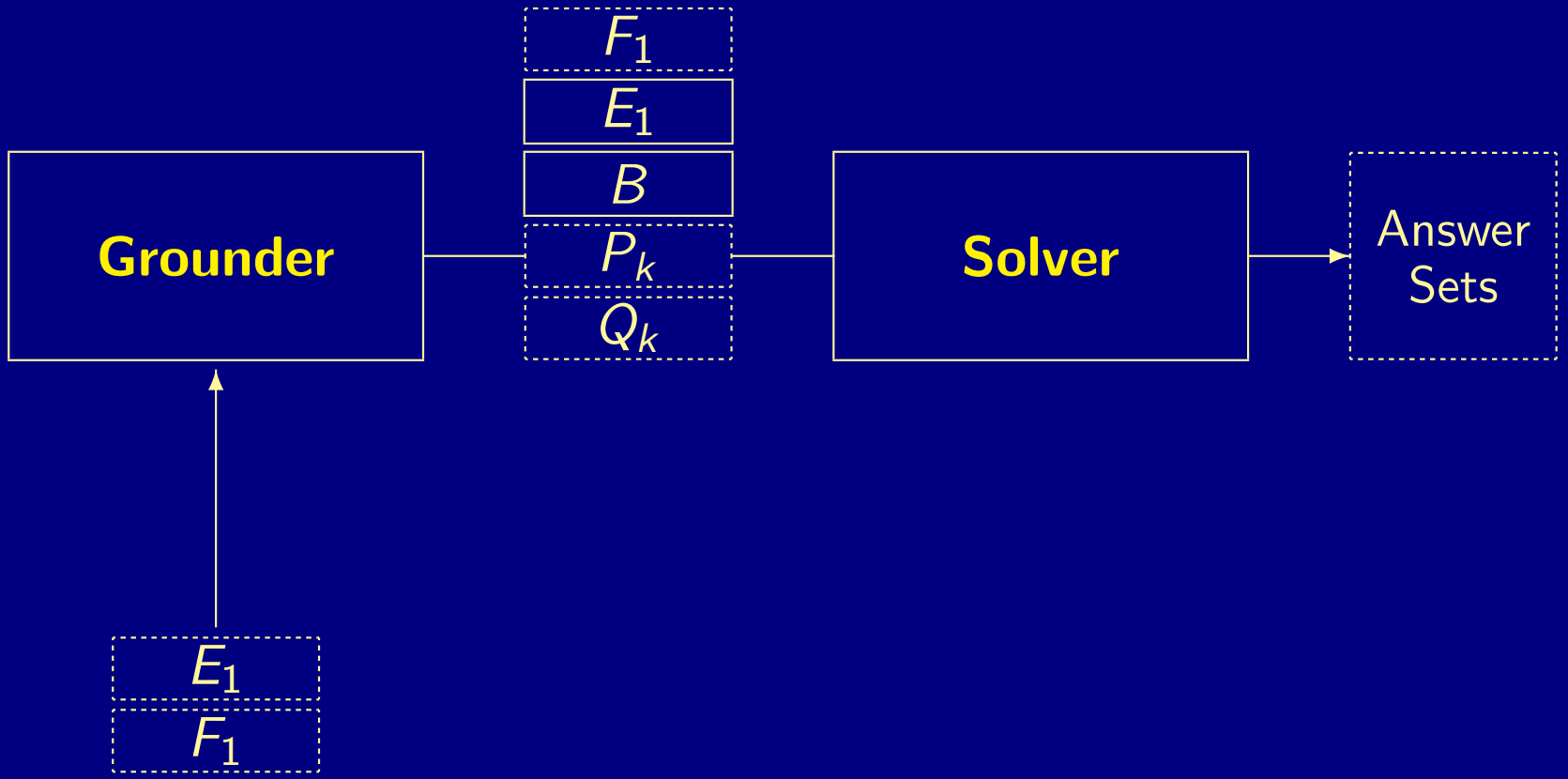

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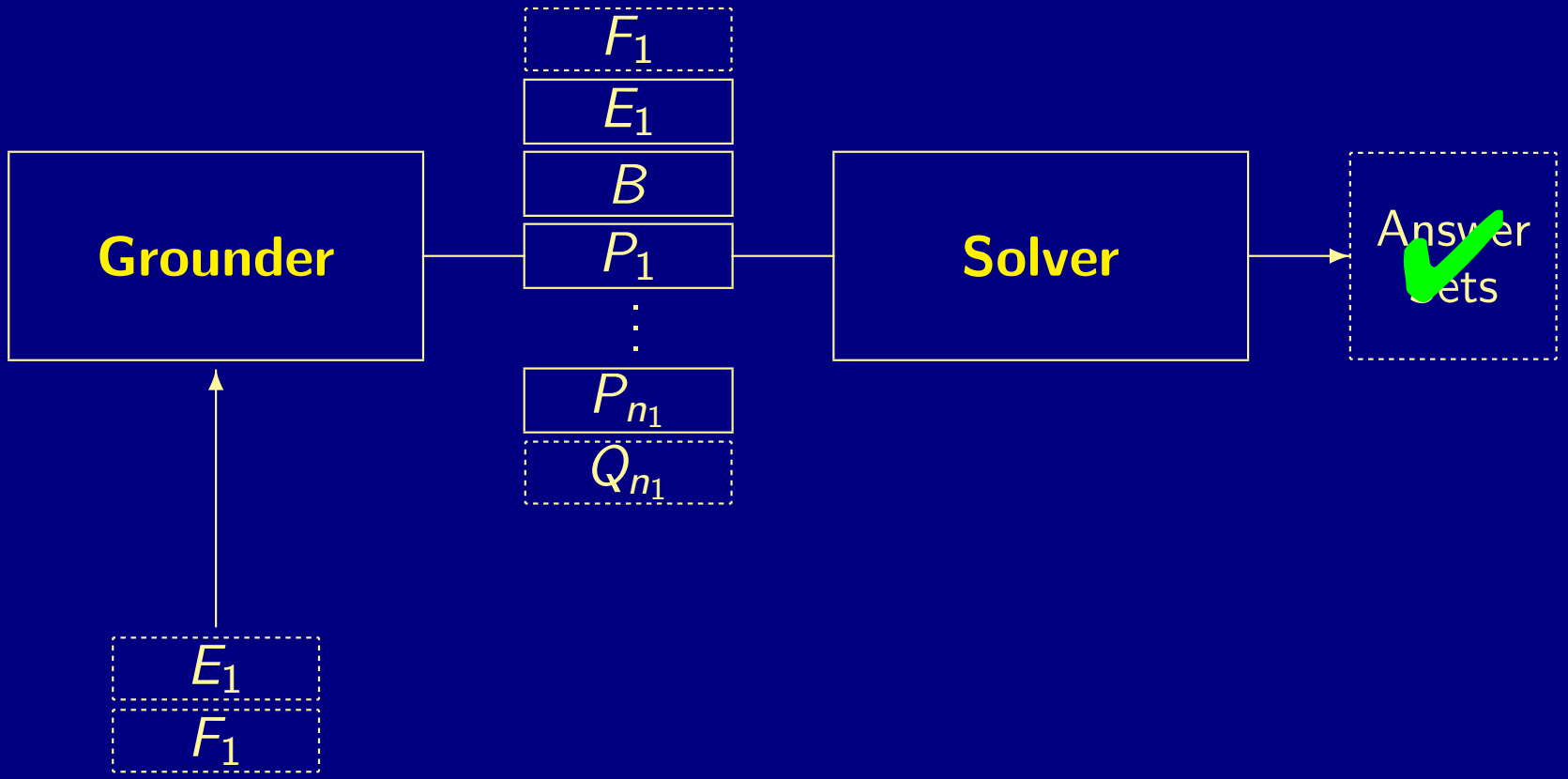

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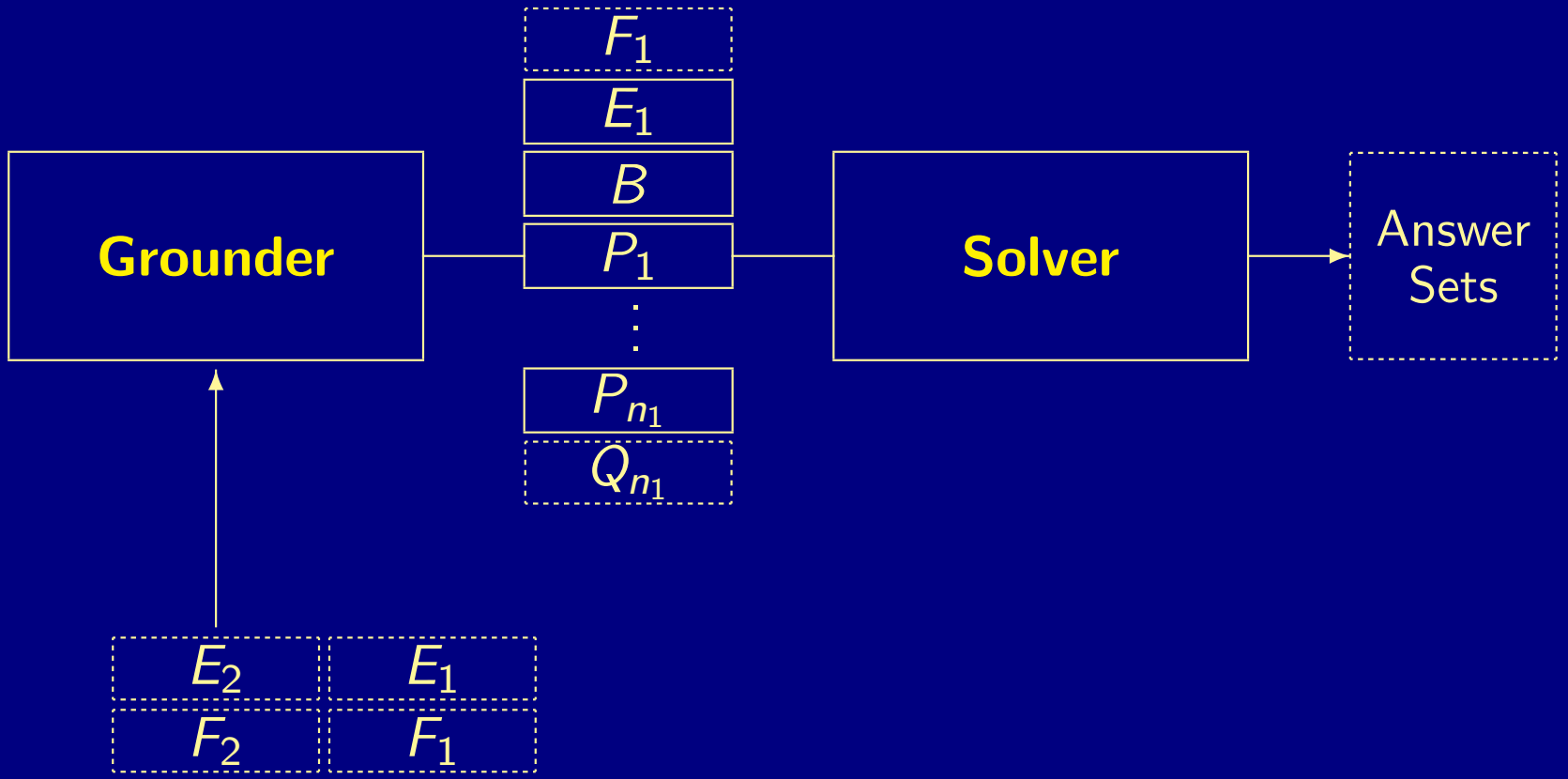

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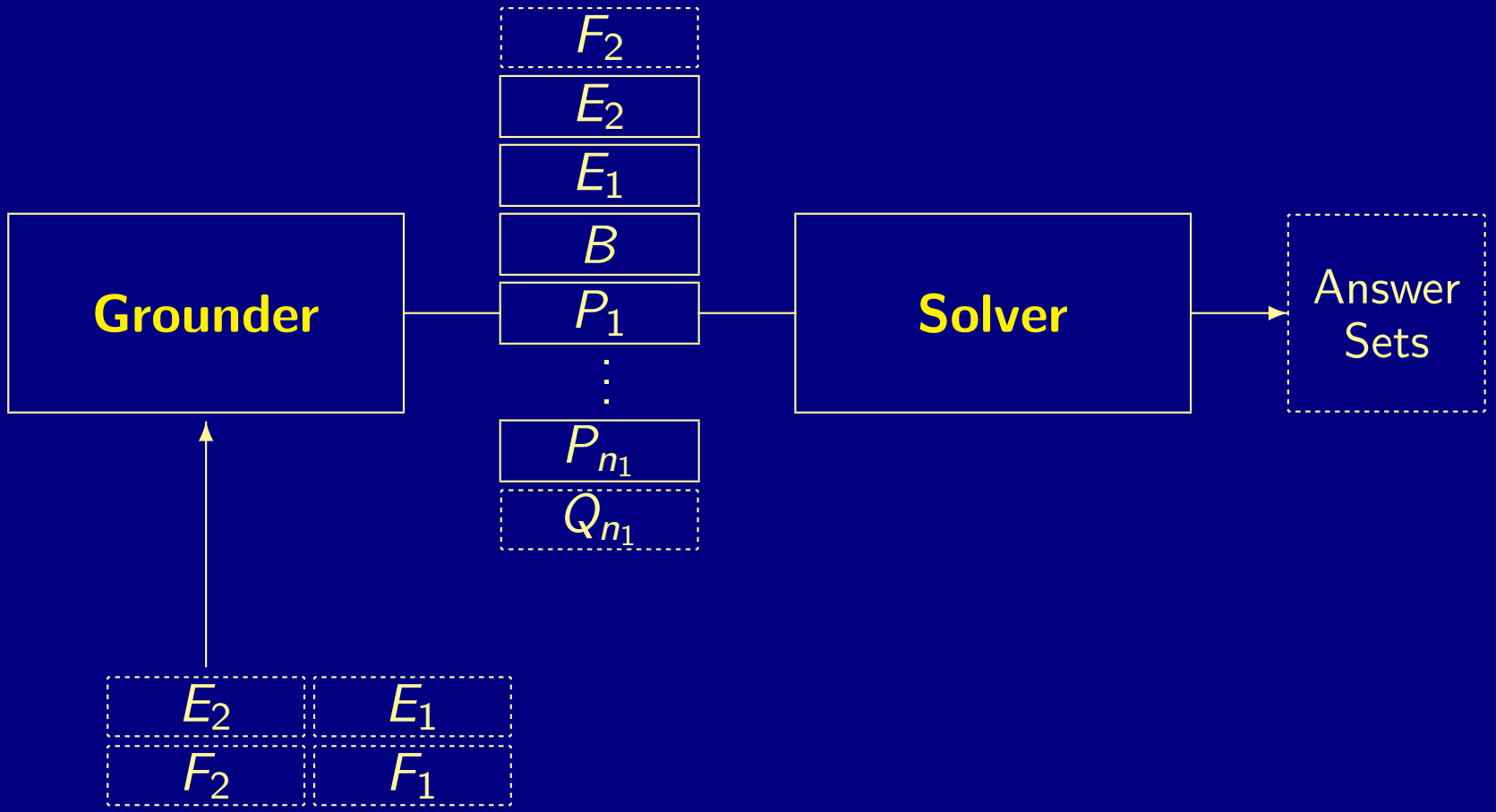

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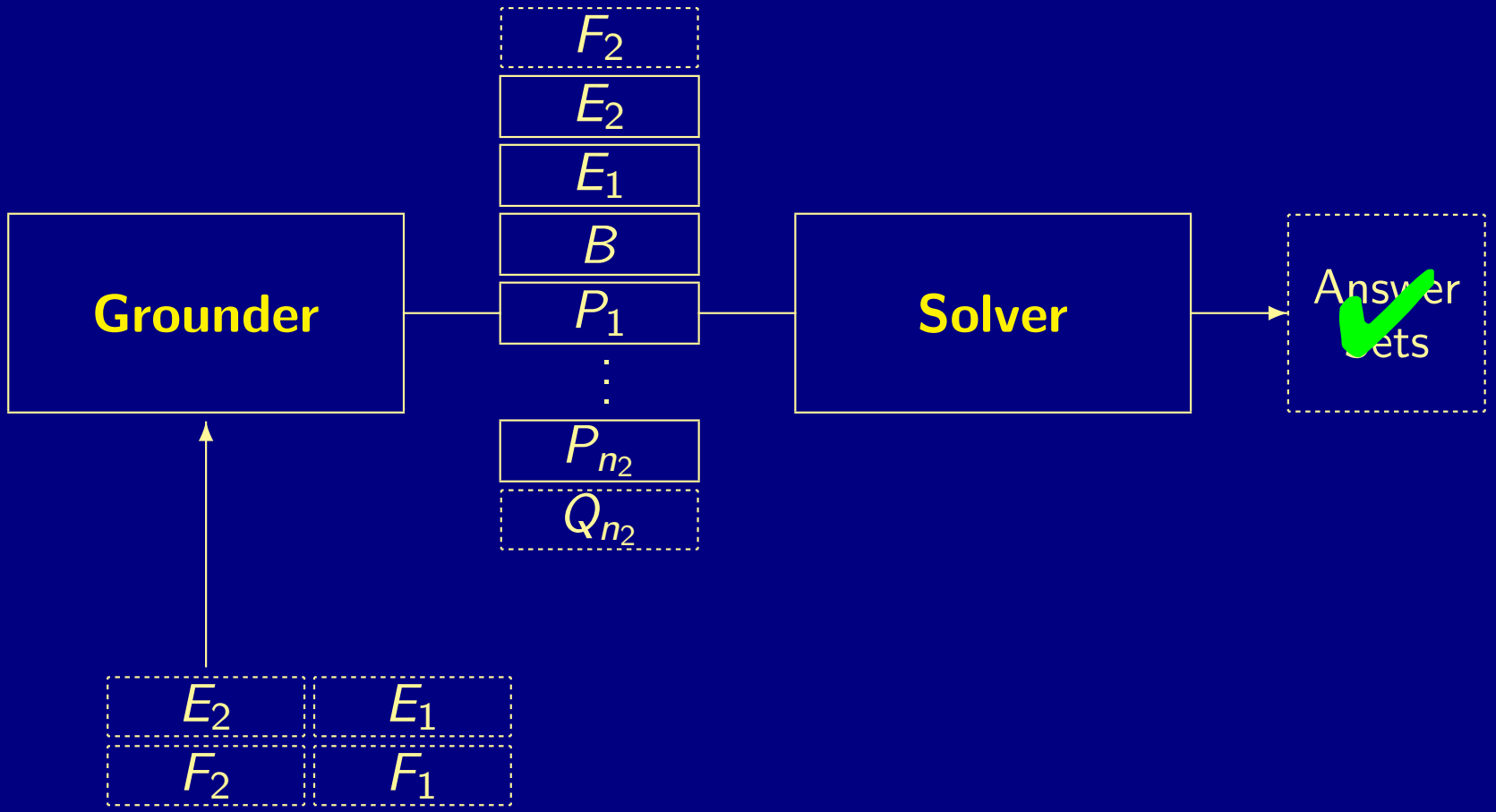

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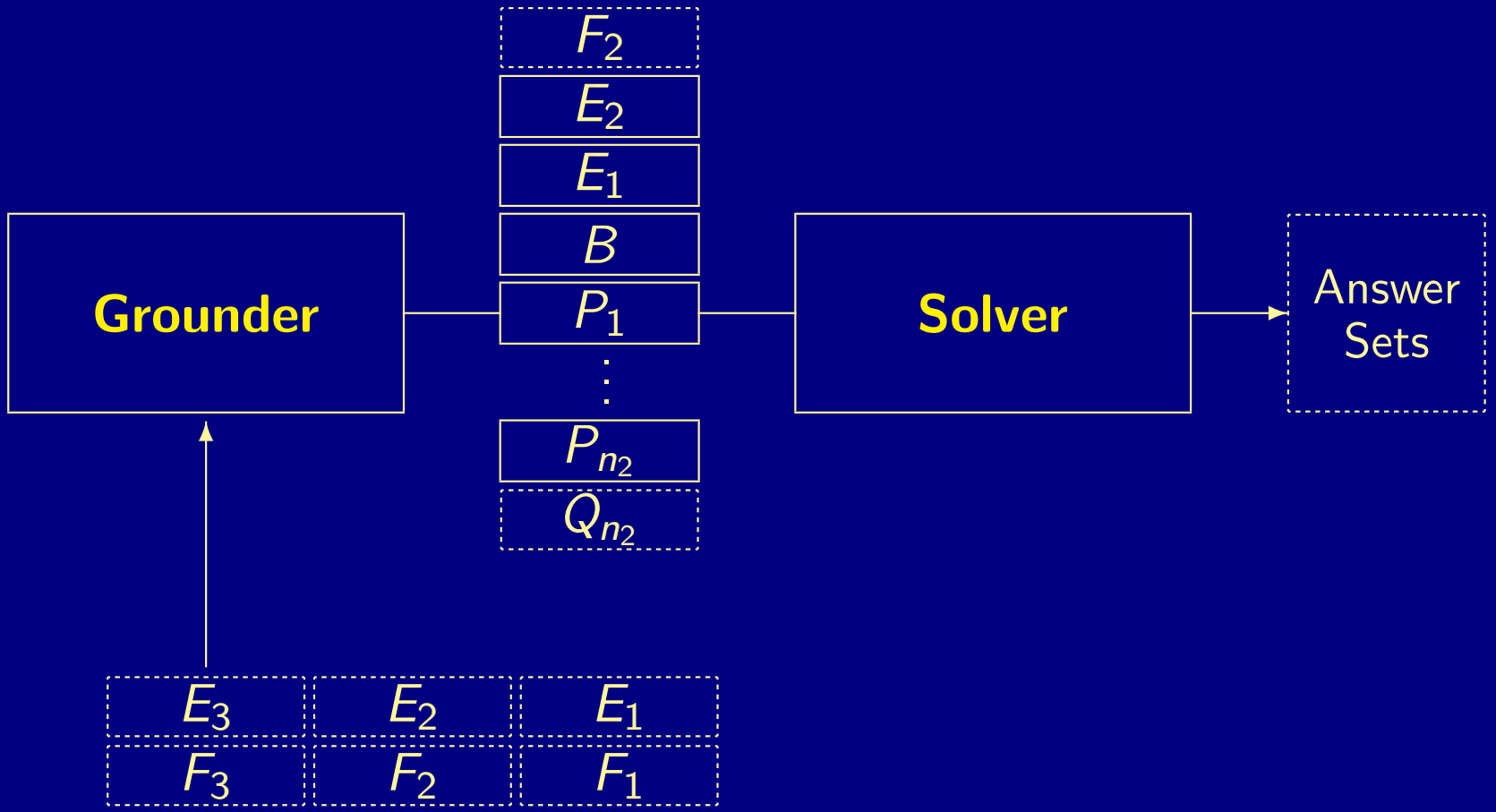

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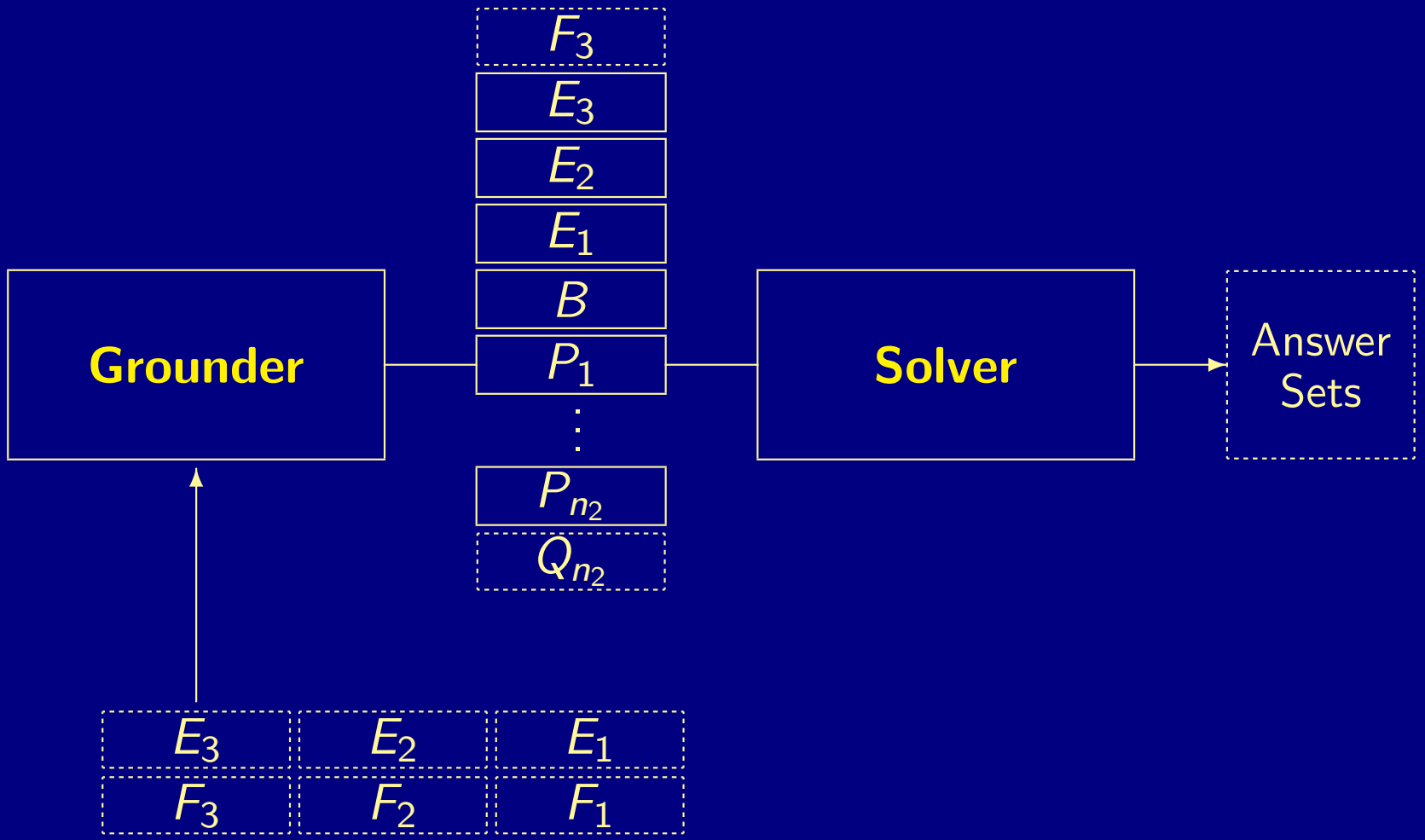

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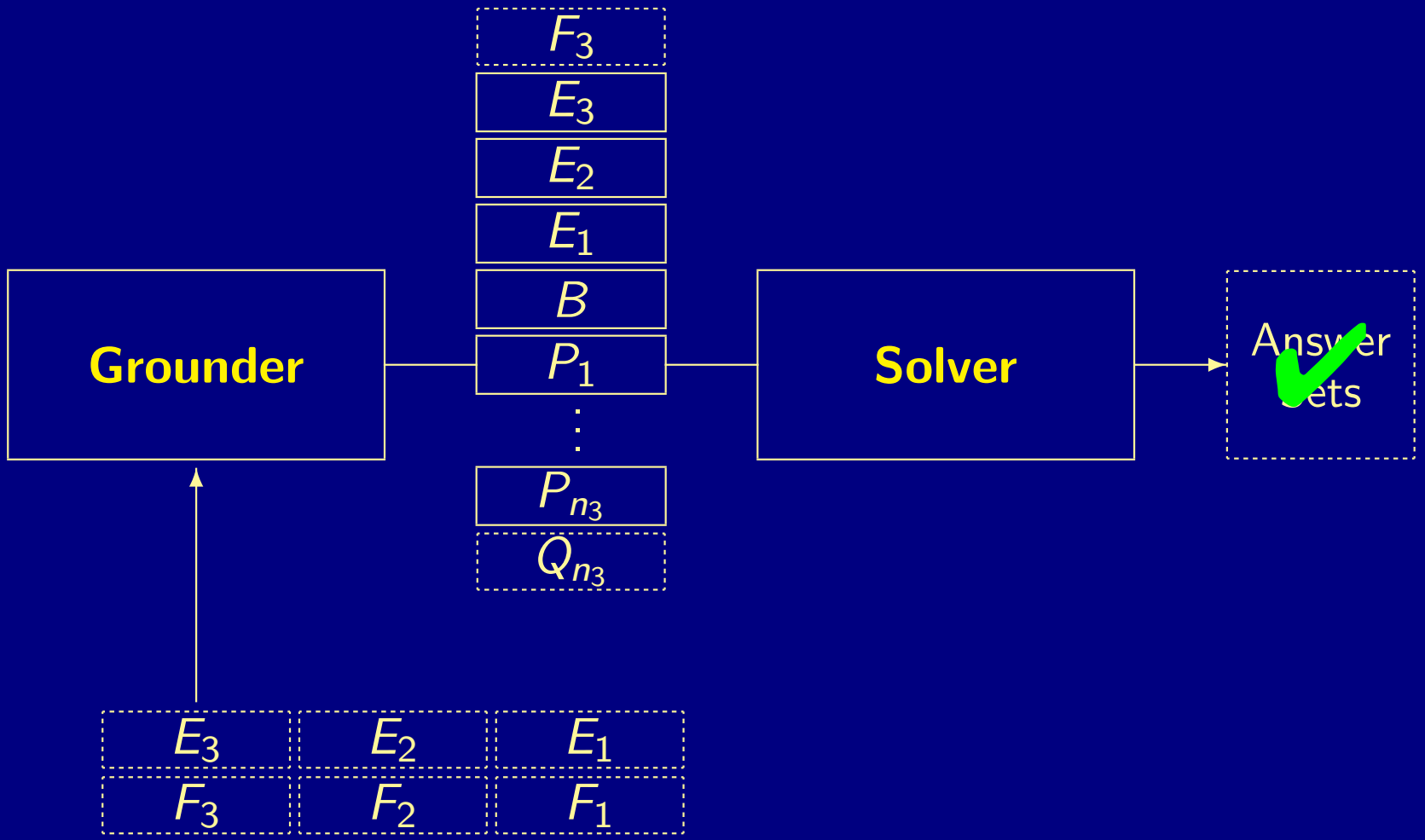

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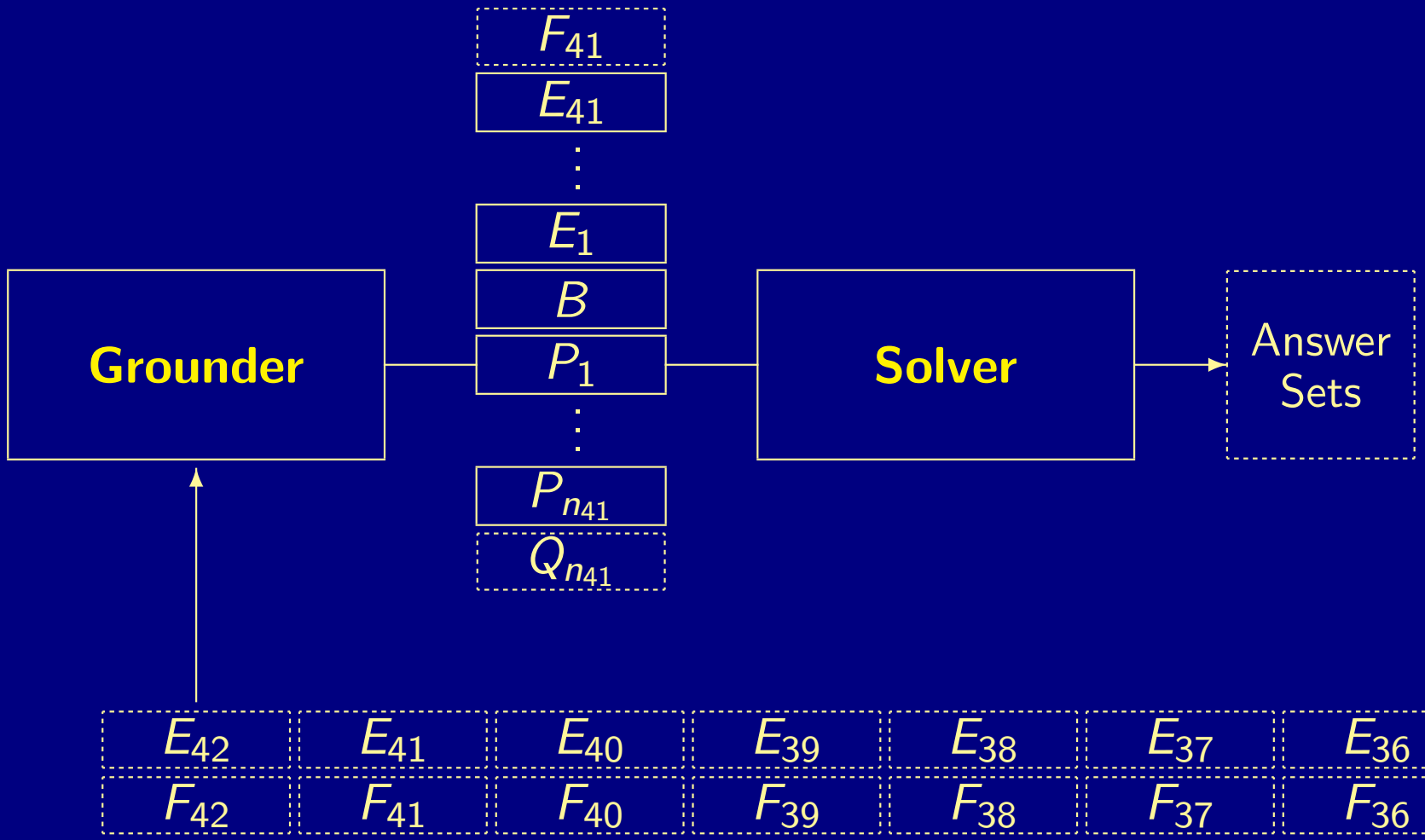

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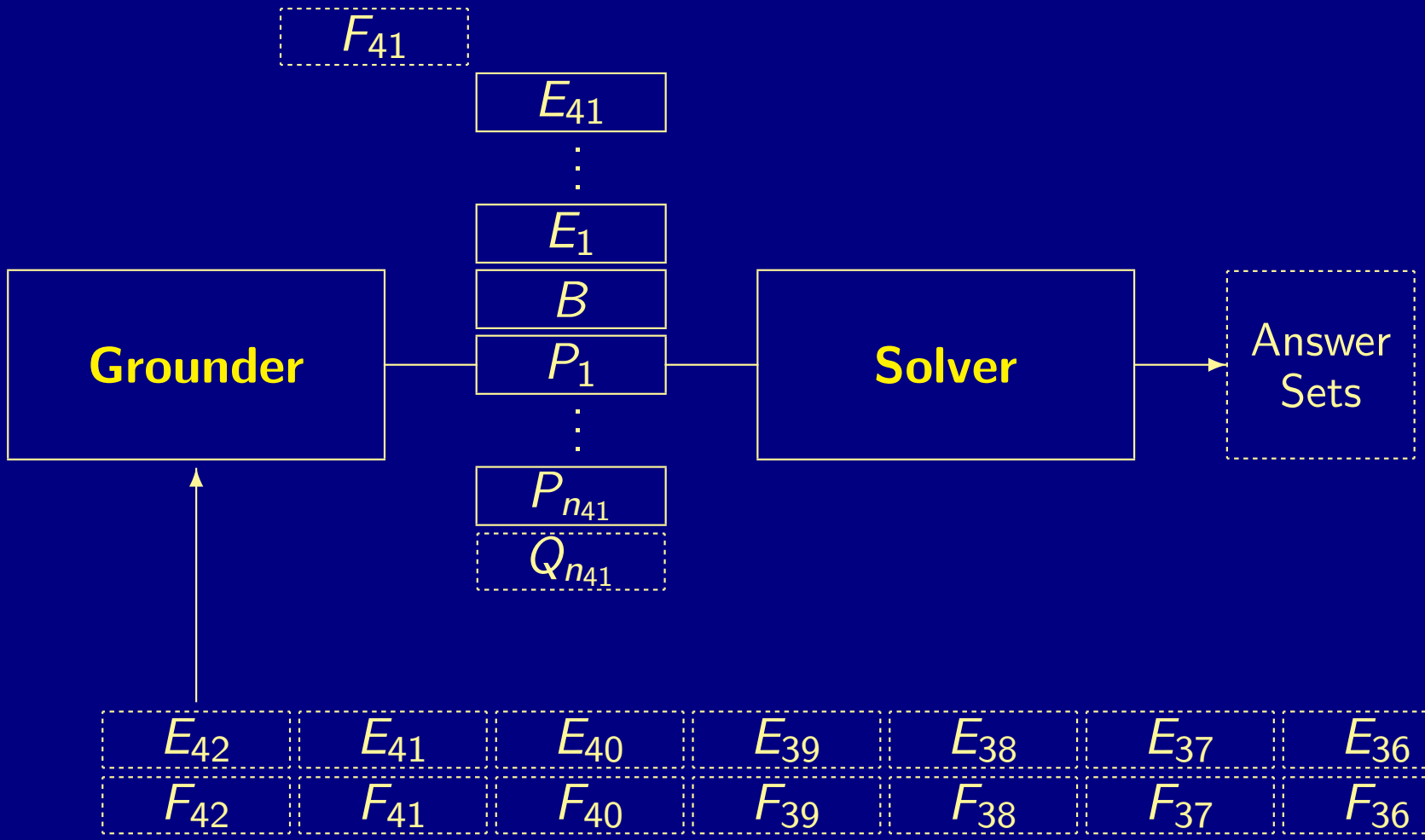

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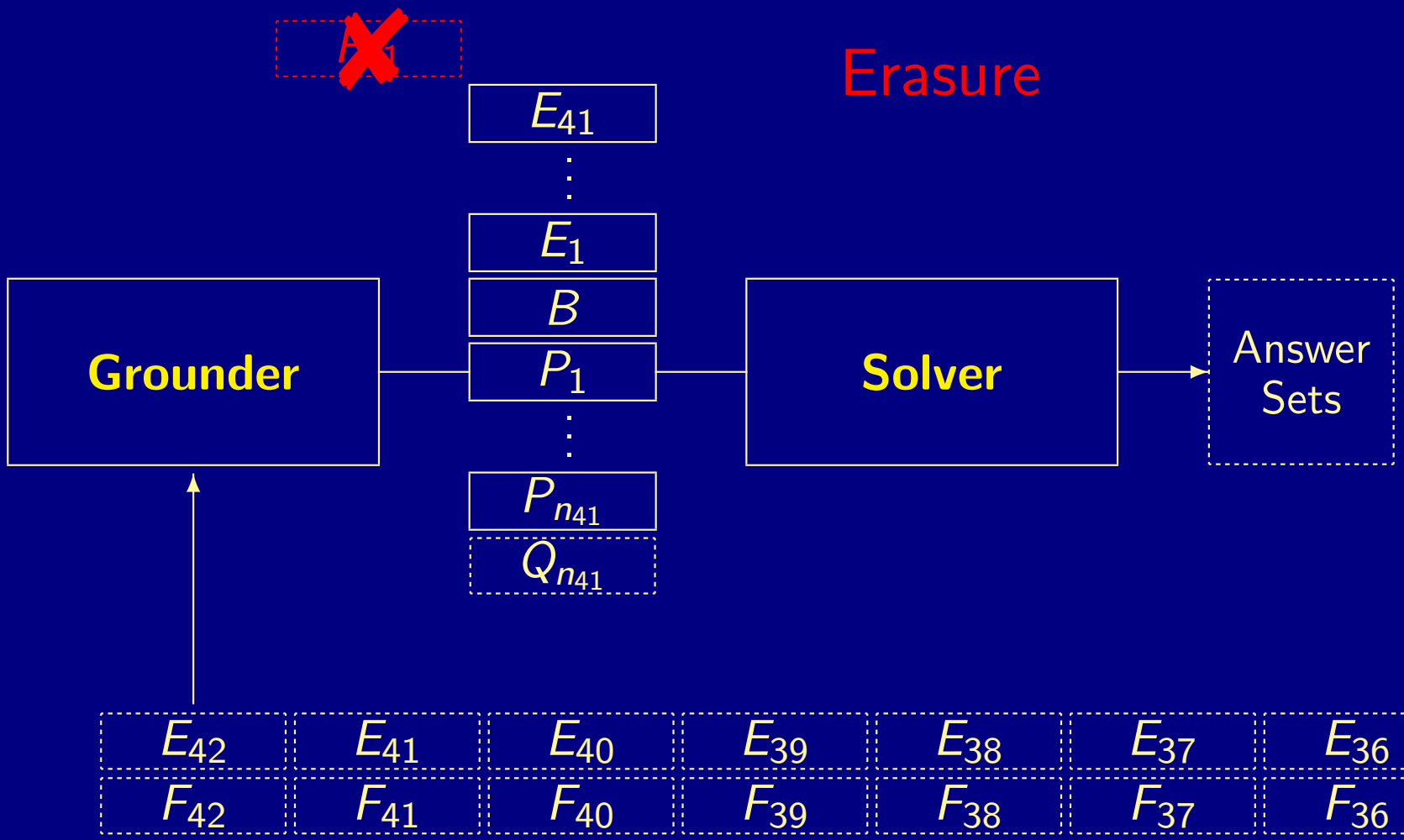

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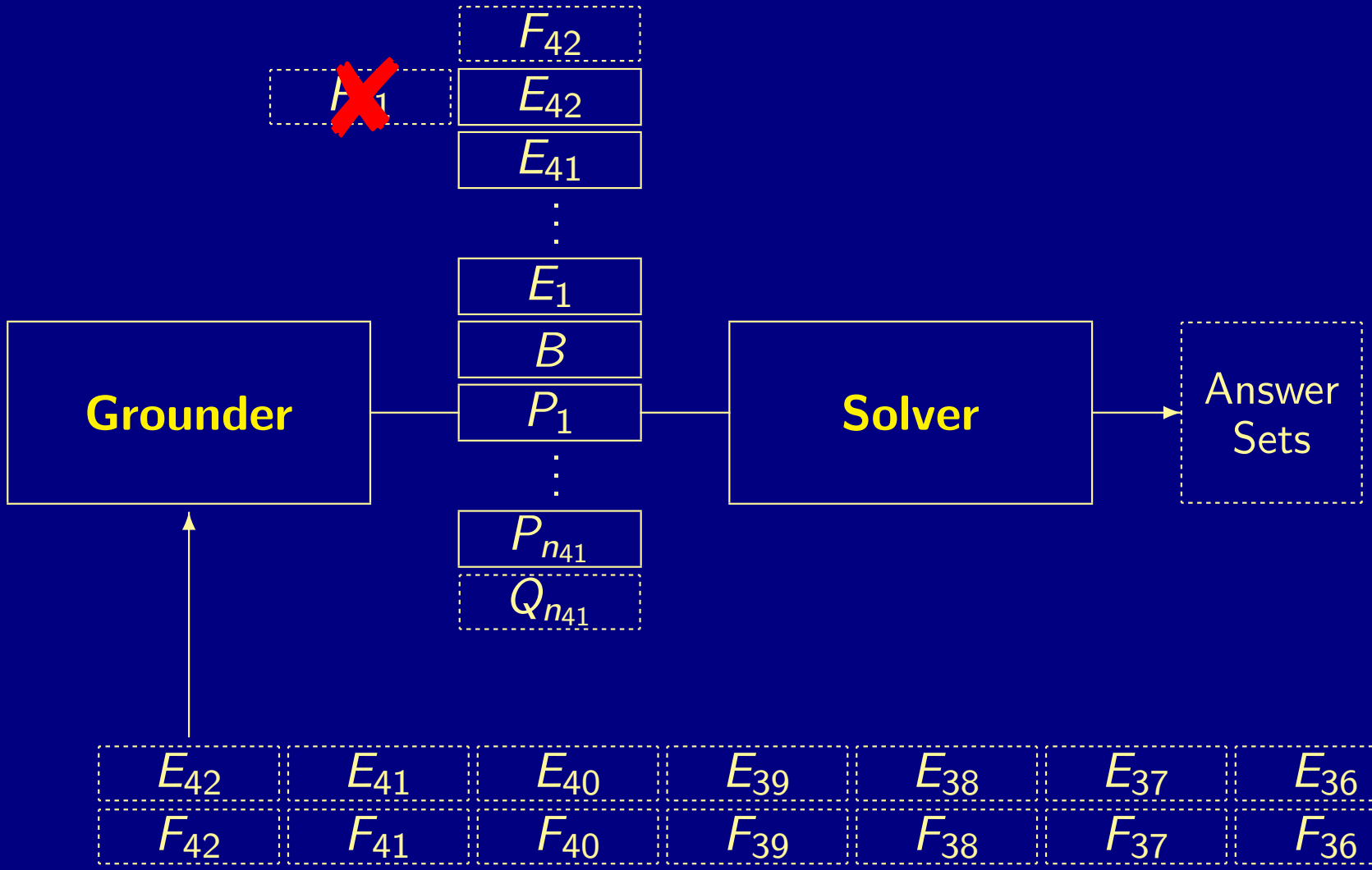

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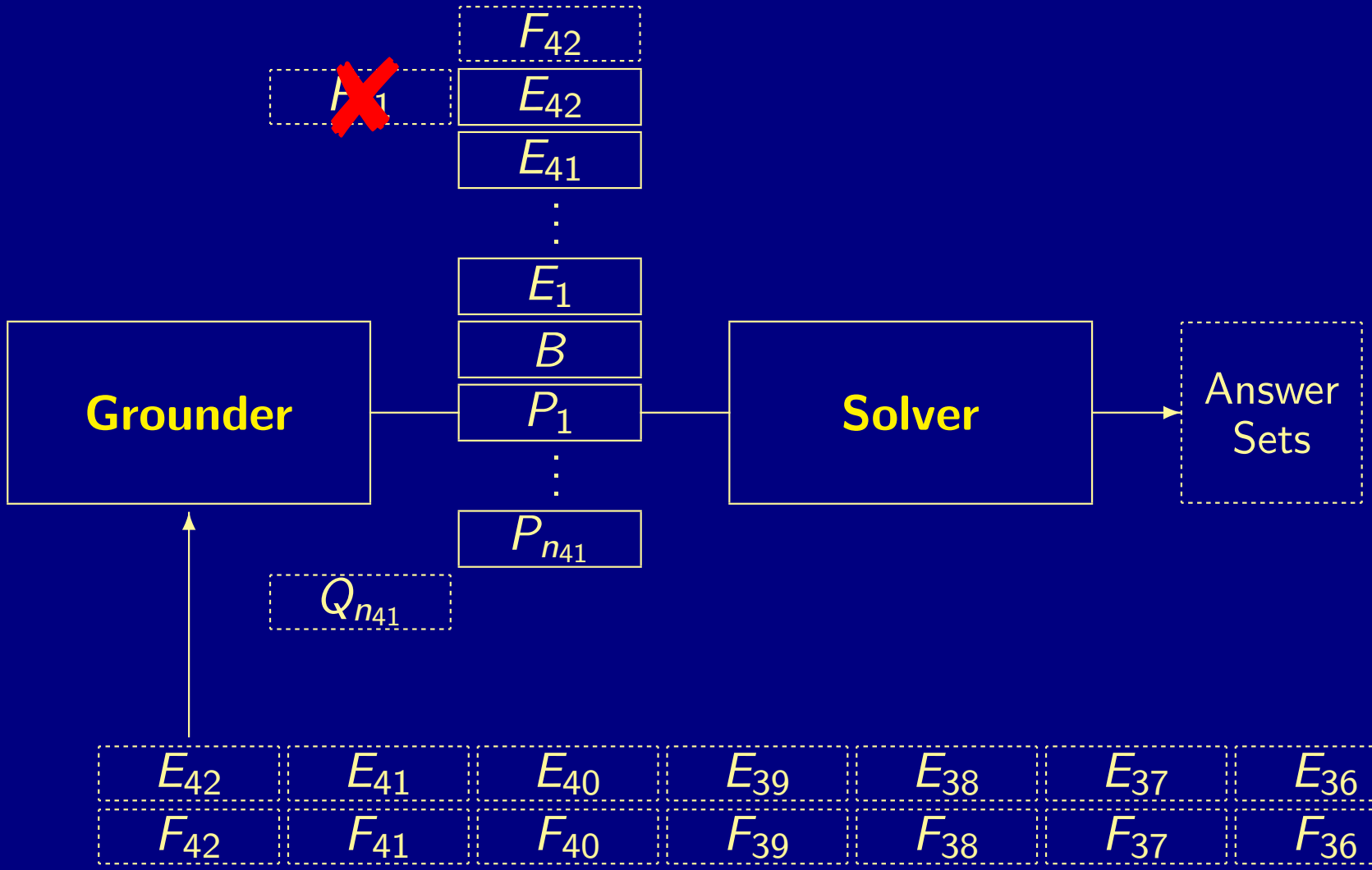

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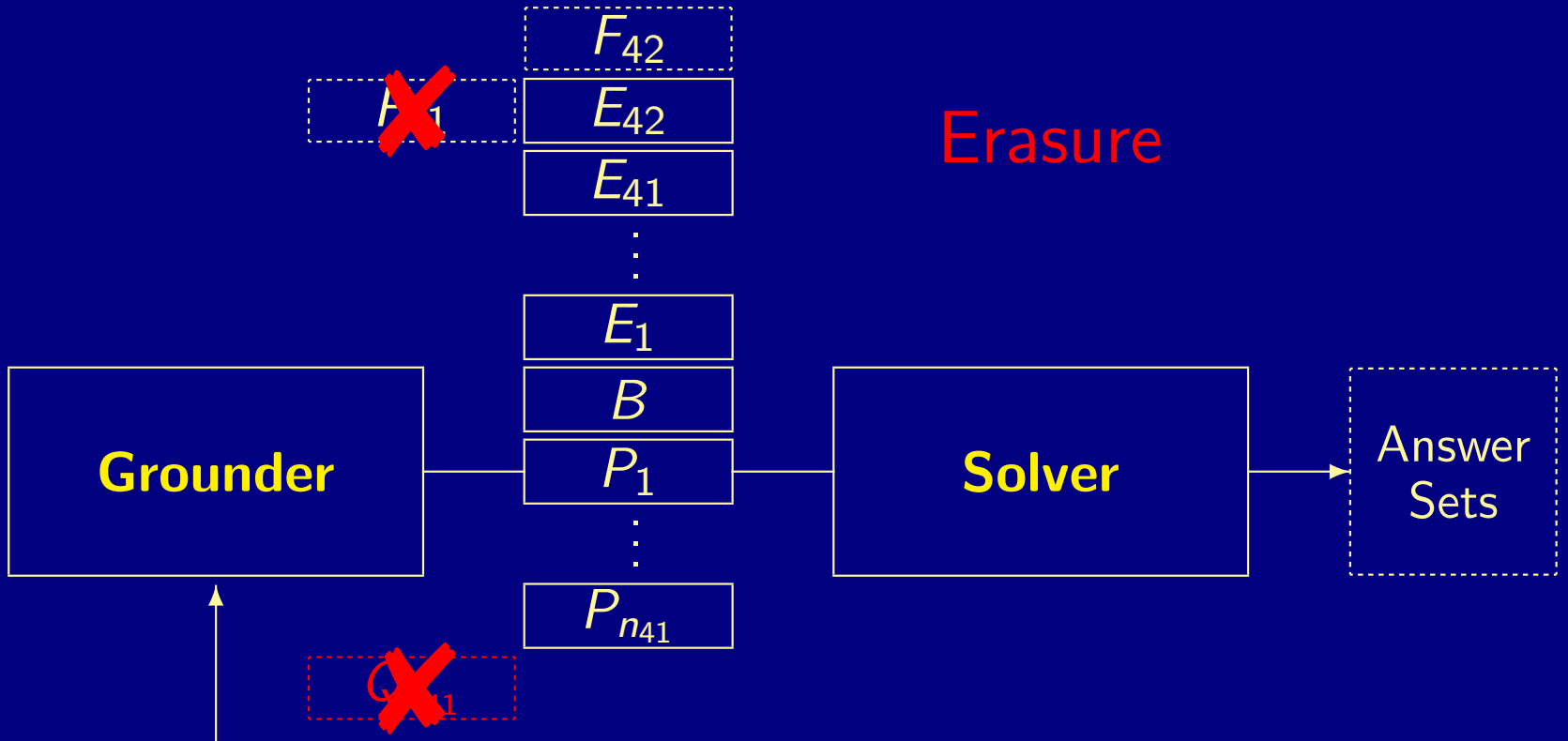

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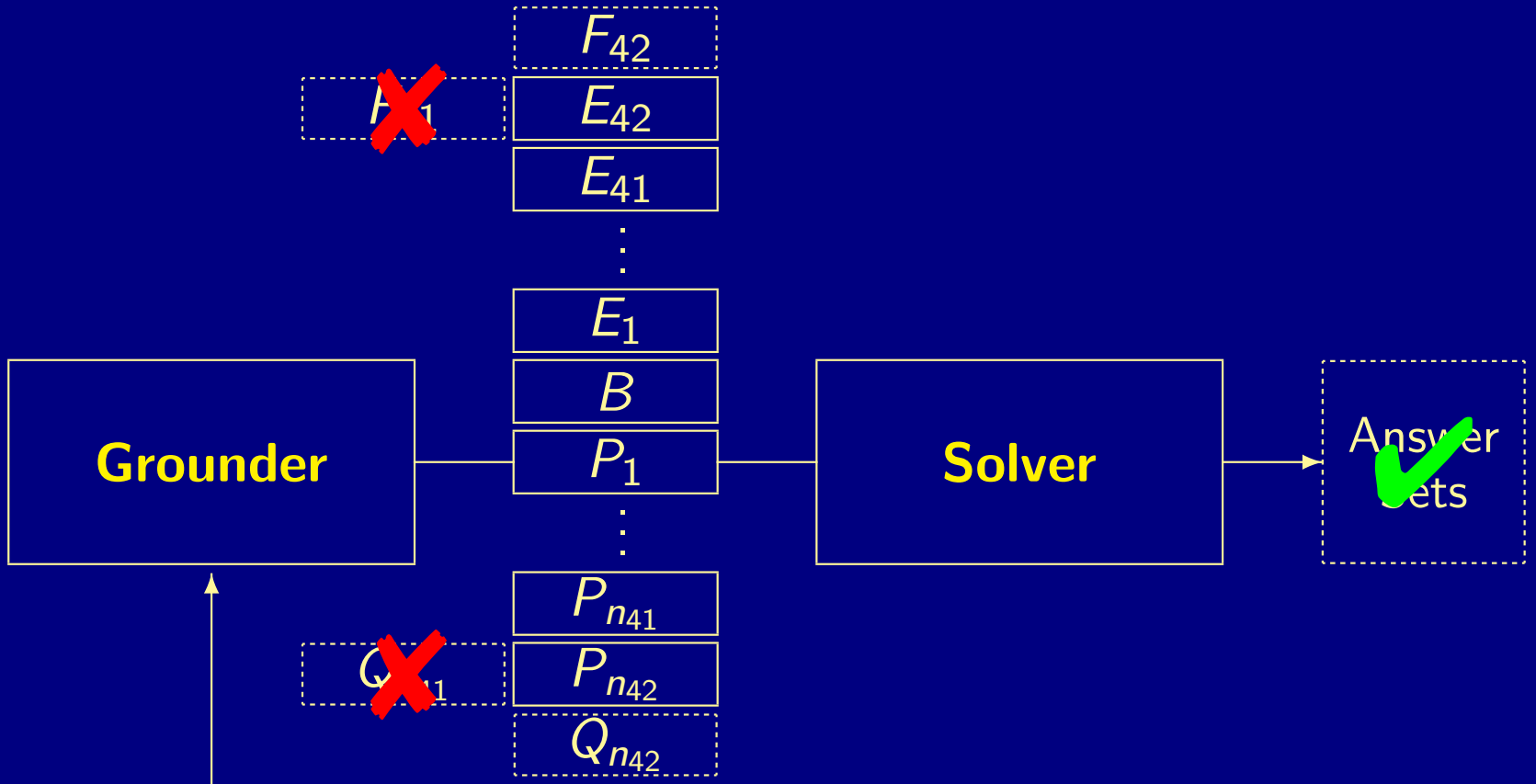

Outline

Sliding Windows

Running Example

- Continuously recognize strings matching: $(a|b)^*aa$

Position	1	2	3	...
Reading	a	a	b	...

- Continuous data flow
- Reasoning over recent data

↪ Focus on time window

Sliding Windows

Running Example

- Continuously recognize strings matching: $(a|b)^*aa$

Position	1	2	3	...
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	✘	✔	✘	

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- Continuously recognize strings matching: $(a|b)^*aa$

Position	1	2	3	...
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Traditional ASP

Running Example

- Continuously recognize strings matching: $(a|b)^*aa$

Position	1	2	3	...
Reading	a	a	b	...
	✘	✔	✘	

Encoding

```
accept :-
    read(a,T),
    read(a,T-1).
```

Data

```
read(a,1).
read(a,2).
read(b,3).
```

Instantiation

```
accept :- read(a,1), read(a,0).
accept :- read(a,2), read(a,1).
accept :- read(a,3), read(a,2).
```

Traditional ASP

Running Example

- Continuously recognize strings matching: $(a|b)^*aa$

Position	1	2	3	...
Reading	*a*	*a*	*b*	...
	✘	✔	✘	

Encoding

```
accept :-
    read(a,T),
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Data

```
read(a,1).
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accept :- read(a,1), read(a,0).
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- Continuously recognize strings matching: $(a|b)^*aa$

Position	1	2	3	...
Reading	*a*	*a*	*b*	...
	✘	✔	✘	

Encoding

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accept :-
    read(a,T),
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```

Data

```
read(a,1).
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read(b,3).
```

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accept :- read(a,1), read(a,0).
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accept :-
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```
read(a,1).
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```

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Running Example

- Continuously recognize strings matching: $(a|b)^*aa$

Position	1	2	3	...
Reading	a	a	b	...
	✘	✔	✘	

Encoding

```
accept :-
    read(a,T),
    read(a,T-1),
not read(a;b,T+1).
```

Data

```
read(a,1).
read(a,2).
read(b,3).
```

Instantiation

```
accept :- read(a,2), read(a,1).

accept :- read(a,3), read(a,2).
```

✘ Data remain persistent !

Traditional ASP

Running Example

- Continuously recognize strings matching: $(a|b)^*aa$

Position	1	2	3	...
Reading	a	a	b	...
	✘	✔	✘	

Encoding

```
accept :-
    read(a,T),
    read(a,T-1),
not read(a;b,T+1).
```

Data

```
read(a,1).
read(a,2).
read(b,3).
```

Instantiation

```
accept :- read(a,2), read(a,1),
          not read(a;b,3).
accept :- read(a,3), read(a,2),
          not read(a;b,4).
```

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Running Example

- Continuously recognize strings matching: $(a|b)^*aa$

Position	1	2	3	...
Reading	a	a	b	...
	✘	✔	✘	

Encoding

```
accept :-
    read(a,T),
    read(a,T-1),
not read(a;b,T+1).
```

Data

```
read(a,1).
read(a,2).
read(b,3).
...
```

Instantiation

```
accept :- read(a,2), read(a,1),
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accept :- read(a,3), read(a,2),
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(Simplified) Reactive ASP

Running Example

- Continuously recognize strings matching: $(a|b)^*aa$

Position	1	2	3	...
Reading	a	a	b	...
	✘	✔	✘	

Encoding[t]

```
accept :-
    read(a,t),
    read(a,t-1),
not read(a;b,t+1).
```

E-Data

```
read(a,1).
read(a,2).
read(b,3).
...
```

Instantiation

```
accept :- read(a,2), read(a,1),
          not read(a;b,3).
accept :- read(a,3), read(a,2),
          not read(a;b,4).
```

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- Continuously recognize strings matching: $(a|b)^*aa$

Position	1	2	3	...
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	✘	✔	✘	

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accept :-
    read(a,t),
    read(a,t-1),
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```
read(a,1).
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...
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```
accept :- read(a,2), read(a,1),
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Running Example

- Continuously recognize strings matching: $(a|b)^*aa$

Position	1	2	3	...
Reading	a	a	b	...
	✘	✔	✘	

Encoding[t]

```
accept :-
    read(a,t),
    read(a,t-1).
```

F-Data

```
read(a,1).
read(a,2).
read(b,3).
...
```

Instantiation

```
accept :- read(a,1), read(a,0).
accept :- read(a,2), read(a,1).
accept :- read(a,3), read(a,2).
```

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Running Example

- Continuously recognize strings matching: $(a|b)^*aa$

Position	1	2	3	...
Reading	*a*	*a*	*b*	...
	✘	✔	✘	

Encoding[t]

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accept :-
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✘ Data must be replayed !

(Simplified) Reactive ASP

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NEW (Simplified) Stream ASP

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NEW (Simplified) Stream ASP

Running Example

- Continuously recognize strings matching: $(a|b)^*aa$

Position	1	2	3	...
Reading	a	a	b	...
	✘	✔	✘	

Encoding[t]

```
accept :-
    read(a,t),
    read(a,t-1).
```

F:L-Data

```
read(a,1).
read(a,2).
read(b,3).
...
```

Instantiation

```
accept :- read(a,1), read(a,0).
accept :- read(a,2), read(a,1).
accept :- read(a,3), read(a,2).
```

✘ Data must be replayed !

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F:2-Data

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	✘	✔	✘	

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```

- **Seamless integration of online data with offline encoding !**

Outline

Discussion

- We provide
  1. Language
  2. Semantics
  3. Modeling techniques
  4. (Prototype) implementation

  for transparent grounding and solving of (time-decaying) logic programs w.r.t. emerging/expiring stream data
- Future work addresses
  1. Data cleansing
  2. Query answering
  3. Optimization support

➥ ASP technology for knowledge-intense stream reasoning

- Application areas include
  1. Ambient Assisted Living
  2. Robotics Planning and Control
  3. Policy Monitoring and Enforcement
  4. etc.