A Novel Architecture for Situation Awareness Systems

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Situation Awareness

Situation Awareness (SA) is concerned with the perception of elements of their meaning and the projection of their status in the near future
[Endsley, 1995]

- Support for decision making in complex, dynamic areas
- Aviation, Air Traffic Control, Power Plant Operations, Military Command and Control
- Mitigate risk of human error
- Own set of conferences, journals

Project Background

- Joint project with Australia's Defence Science and Technology Organisation (DSTO)
- DSTO approached NICTA for help to build a system for **higher-level** situation awareness based on automated reasoning techniques
  - Go beyond state-of-the-art
  - Run as a one year pilot project
- Project outcome: **SAIL**
  - "Situation Awareness by Inference and Logic"
  - Novel architecture and prototype implementation following a "knowledge-based" declarative approach

Atlantis Scenario

- Detailled information on an evolving conflict on Atlantis
  - Geographical and political
  - Operational (air corridors) and military (assets, capabilities)
  - Sensor data (radar), spy reports
- Challenge: to reconstruct/analyse the **event list**

+20	2000	75th Air Defence Squadron in Cambonga moves 8 x SA-10 and 8 x SA-12 to Eaglevista via rail and roads.
+21	2000	Task Group leaves North America home port (44N64W) in direction of Atlantis to a position 200 NM off Caltrop seaport (6330N 2730W) [1827 NM @ 15 kts = 122 hrs = 5 days 2 hours][33 hrs to reach Cape Race (495 NM)]
+22	1200	Blueland requests Task Group to escort the cargo from open sea to Celtic Straits.
+23	0500	Task Group waits for Cargo off Cape Race [4600N 5200W]
+23	1600	Cargo reaches Task Group off Cape Race.
+25	1200	Redland's A50-2 takes off from Becker-Bender AFB [5250N 2006W] and flies to Eaglevista.
+25	1320	2 x Su-24E (ECM) take off from Krupali and fly towards Deeland City and then to Eaglevista.

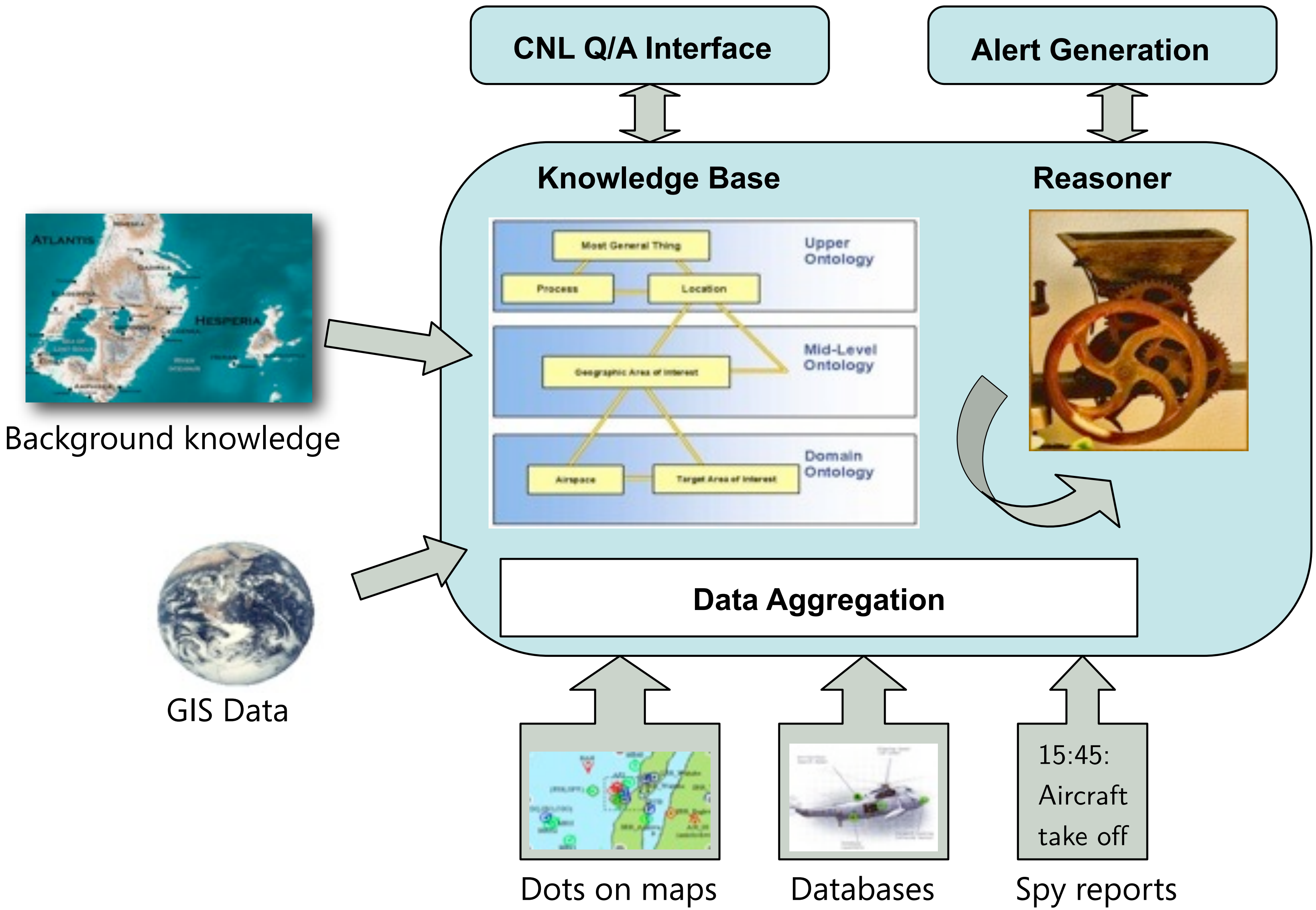
Higher-Level Situation Awareness

Q: What do these dots "mean"?

Higher-Level Situation Awareness

A: An Awacs surveilling a border, a greenpeace vessel

Combining Data/Information Sources



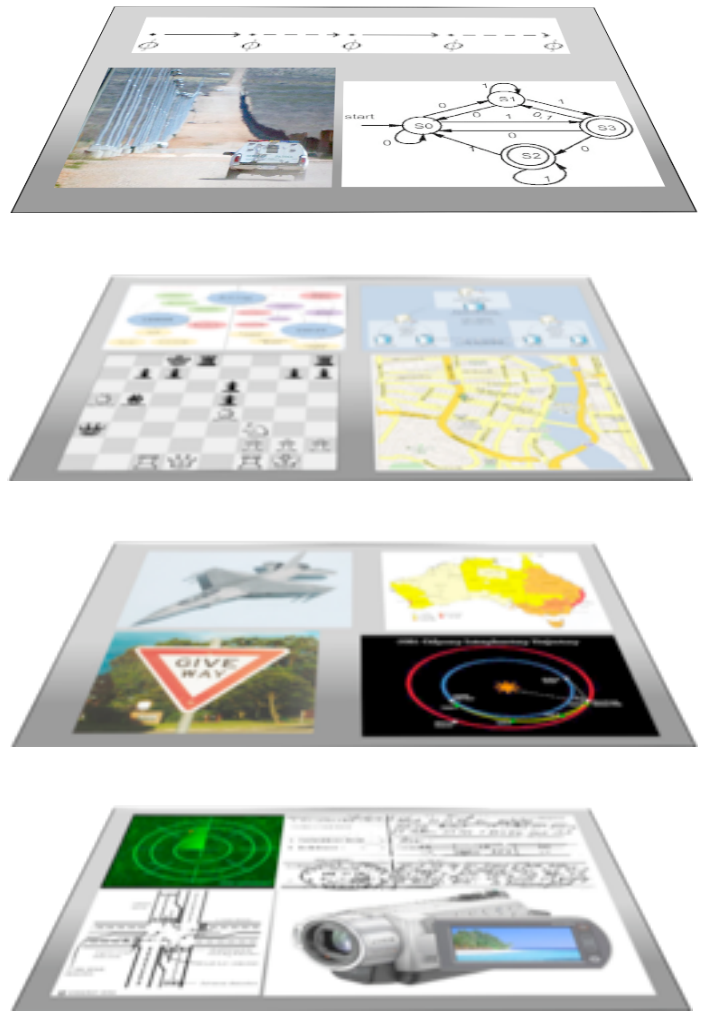
SAIL - System Architecture

Alert Generation
Identify Behaviour

Semantic Analysis
Identify Relations

Data Aggregation
Identify Entities

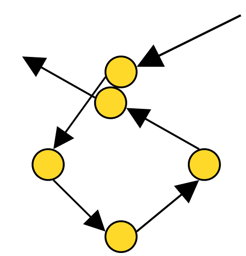
Collect Data



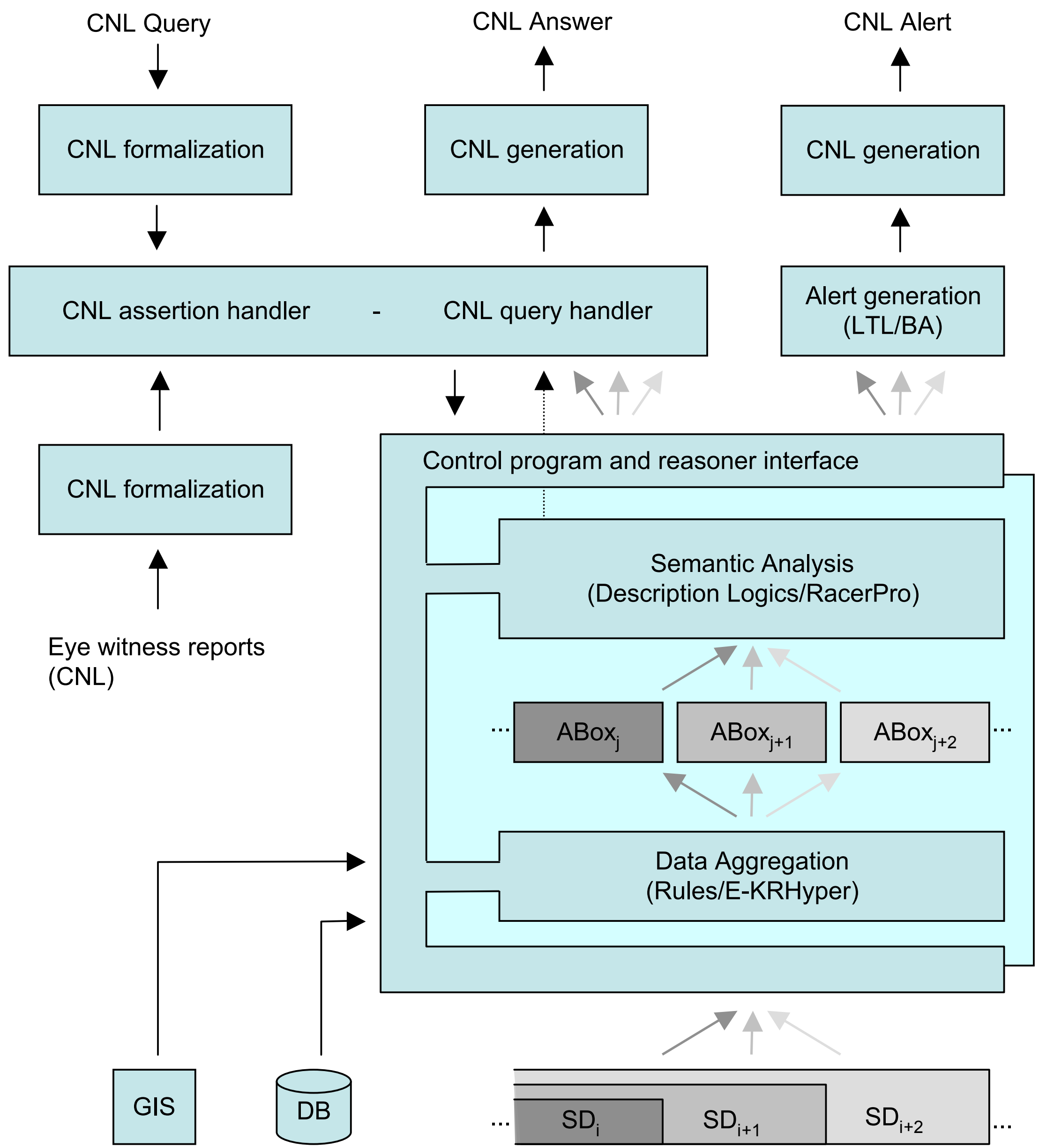
patrols(●, ●)

surveils(●, ●)

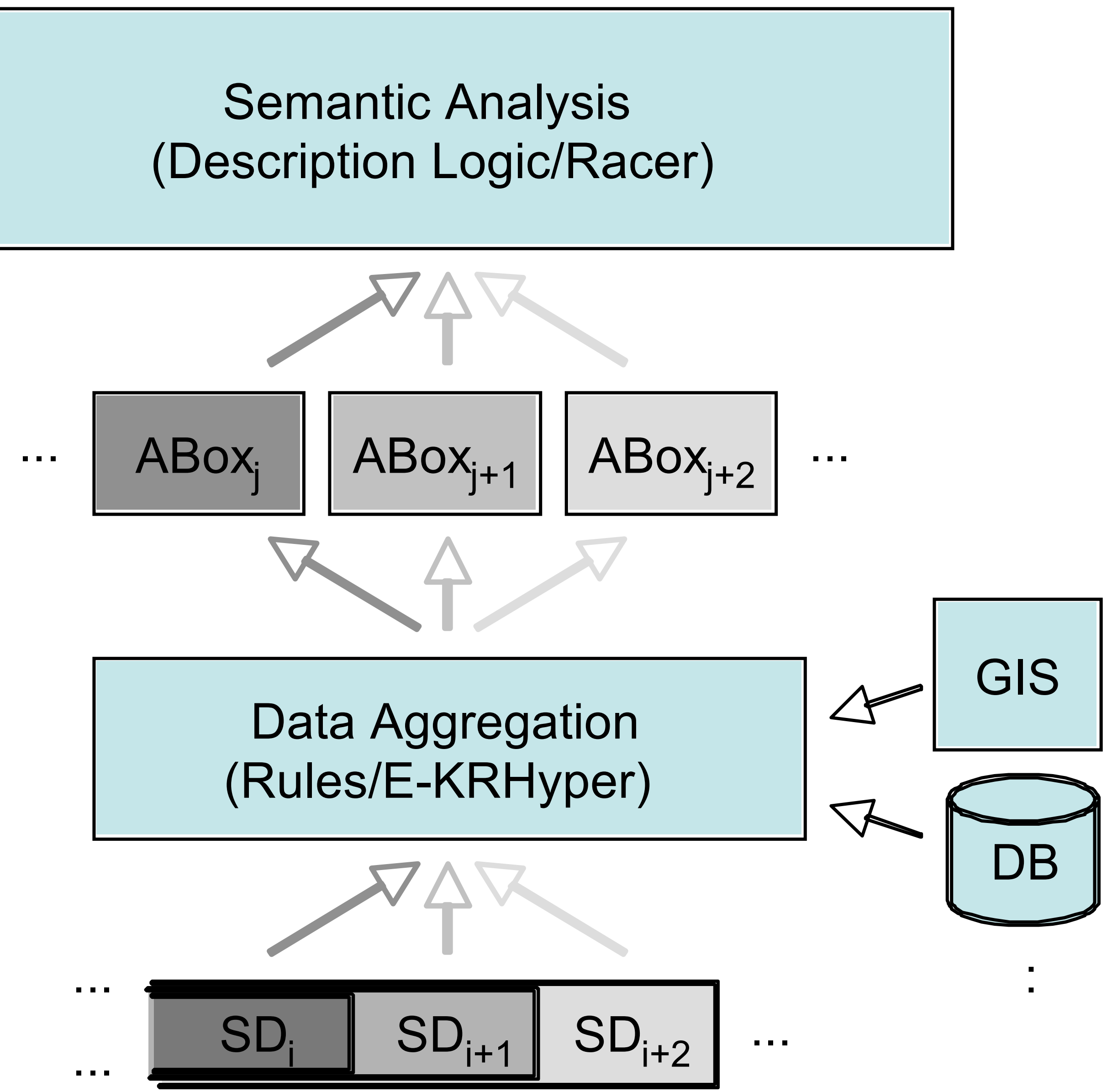
circle(●)



SAIL - System Architecture



Data Aggregation and Semantic Analysis



Data Aggregation

- Control program periodically invokes Data Aggregation layer on incoming Sensor Data (SD)
  - Maintains limited history of previous SD
- Data Aggregation layer analyse information over time
  - Detect capabilities: airstriker, surfacestriker
  - Synthesize events
- Specified as a disjunctive logic program (Rules)
  - Stratified default negation
  - Bottom-up evaluation, via KRHyper
  - Least model specifies an ABox

Data Aggregation Excerpt

```
object_appears(Obj, Now) :-
      current_time(Now),  % supplied by control program
      object(Obj, Now),   % Obj is in SD_Now
      previous_time(Now, T),
      \+ object(Obj, T).

take_off(Event, Obj, Now) :-
      object_appears(Obj, Now),
      in_air(Obj, Now),  % in_air computed by GIS
      concat(['ev_',Obj,'_',Now],Event).

%% assemble resulting ABox
abox(take_off(Event)) :- take_off(Event, Obj, Time).
abox(time(Even, Time)) :- take_off(Event, Obj, Time).
abox(object(Even, Obj)) :- take_off(Event, Obj, Time).
```

This is not Prolog
There is no "goal"

Some More Features

- Preserve information over time

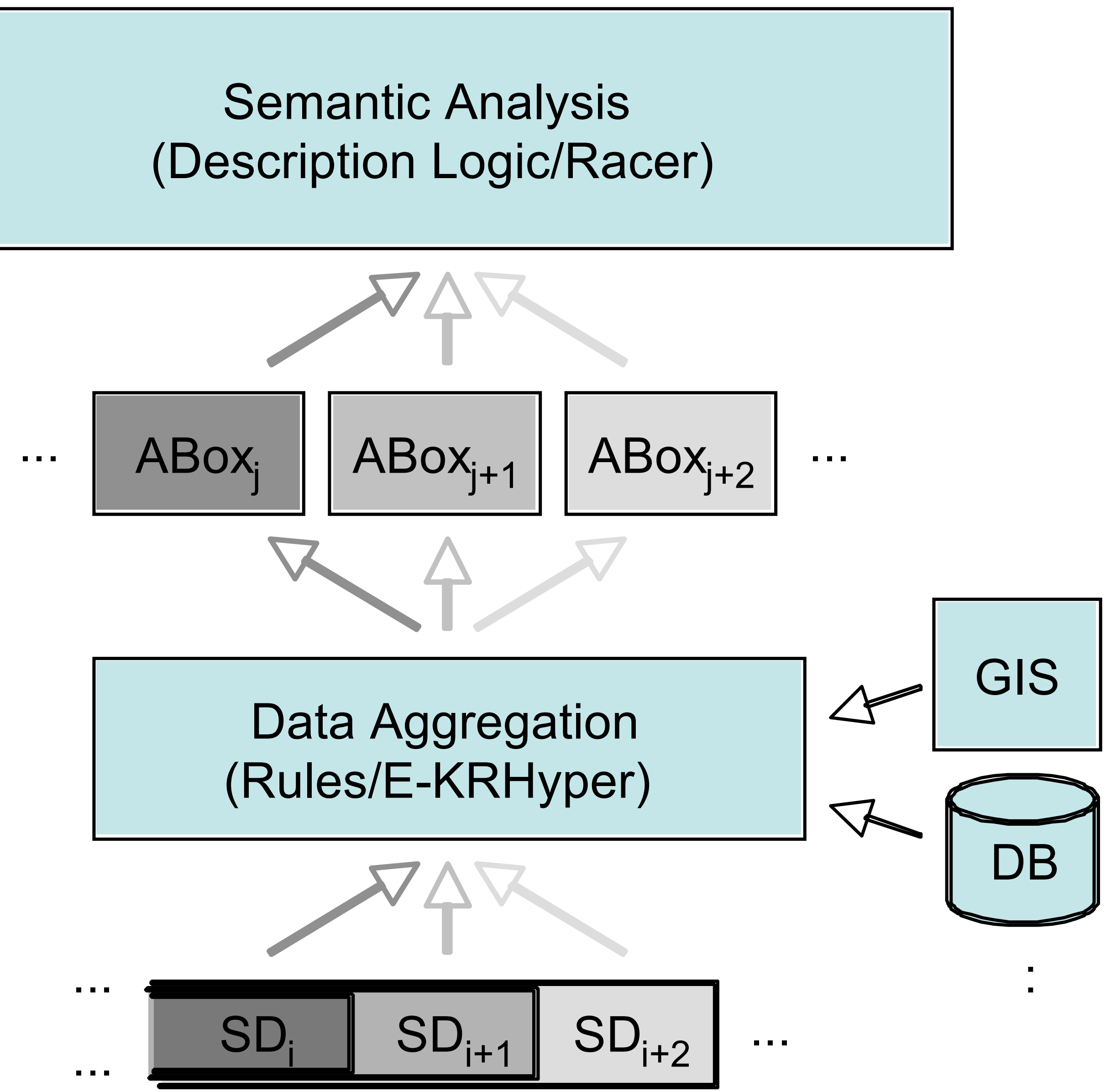
```
reassert(take_off(Event, Obj, CreationTime)) :-
   take_off(Event, Obj, CreationTime),
   current_time(Time),
   object(Obj, Time).  % reassert as long as Obj exists
```

- Can `Obj` reach `City`?

  For that, need to know

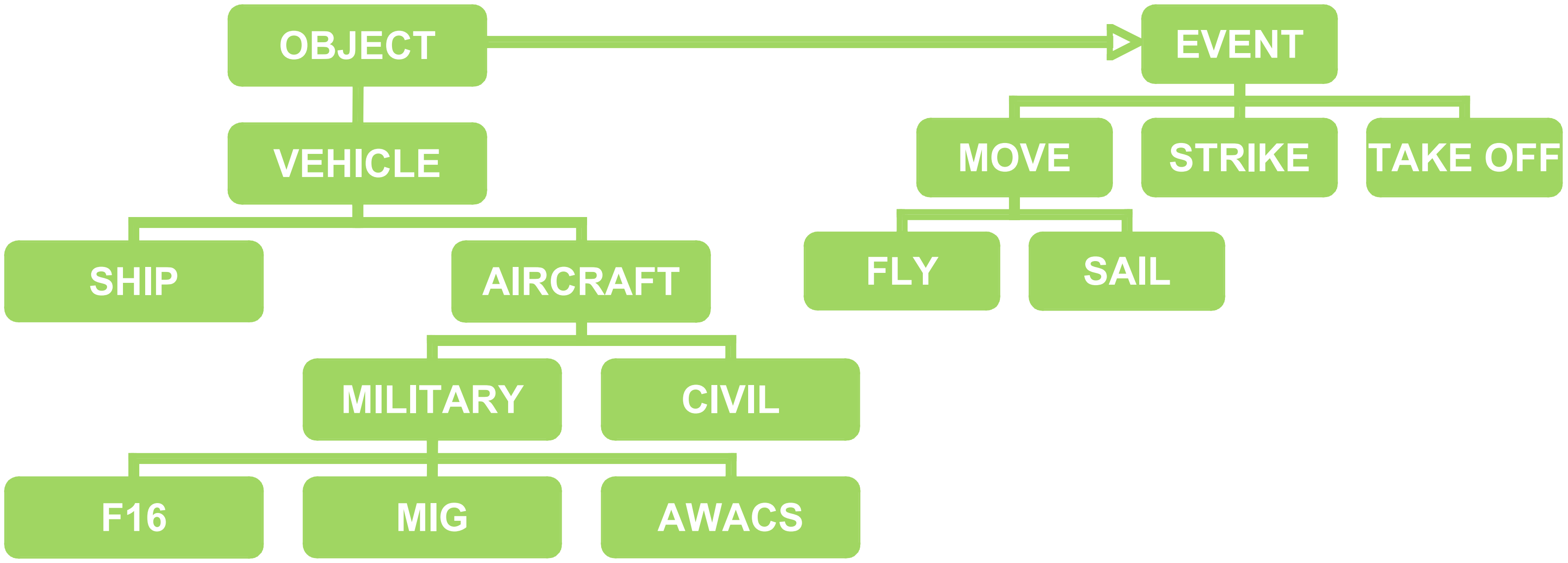
  - Distance between Obj and City, via GIS coupling
  - Time in air, kept in Data Aggregation layer
  - Aircraft capability, from database (facts)

Data Aggregation and Semantic Analysis



Semantic Analysis

- Conceptually higher level than Data Aggregation
  - Concepts e.g. aggresive, threat (holy grail)
  - Roles e.g. associated_with, enemy_organization
- Combines latest ABox and Description-Logic Ontology



Semantic Analysis

Ontology contains

$$\texttt{aggressive} \doteq \exists\ \texttt{has\_target}.\ (\texttt{physical\_object} \sqcup \texttt{space\_region})$$

Data Aggregation provides concept/role assertions

```
has_target(obj1, obj2).
physical_object(obj2).
```

It follows `aggressive(obj1)`

Could do this with Logic Program

Semantic Analysis

Ontology contains

$$\texttt{aggressive} \doteq \exists\ \texttt{has\_target}.\ (\texttt{physical\_object} \sqcup \texttt{space\_region})$$

An eye-witness report may provide (non-primitive) assertion

`aggressive(obj1).`

Can't do this (easily) with Logic Program

it follows that `obj1` has a target that is a `physical_object` or a `space_region`

Semantic Analysis

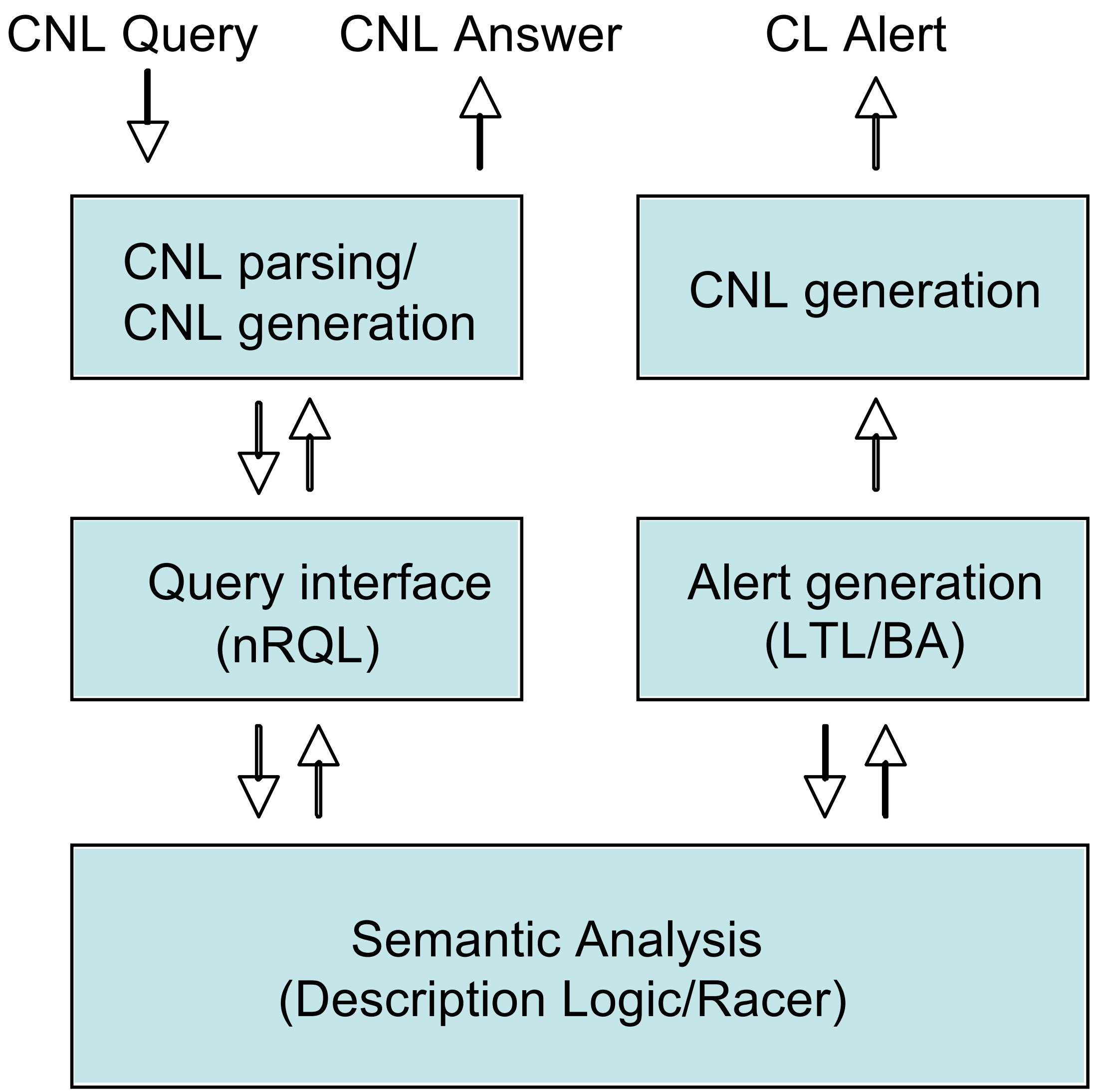
Non-primitive role assertions by means of nRQL rules

"a fighter associated with an enemy of blueland
targets an associate of blueland"

```
(firerule (and (?EM move)
               (?EM ?Ag has_theme)
               (?Ag fighter)
               (?Ag ?Org associated_with)
               (?Org s_blueland enemy_organization)
               (?EM ?Y has_direction)
               (?Y s_blueland associated_with))
   ((related (new-ind aggr ?Ag ?Y) ?Y has_target)))
```

Creates a new individual `aggr-Ag-Y` that is in the `has_target` relation with `Y`

Alert Generation



Alert Generation

- Capture a critical situation
- Are raised automatically by system
- Formally defined via linear temporal logic (LTL)

$$\mathbf{G}(\neg \mathit{aggressive}(p))$$

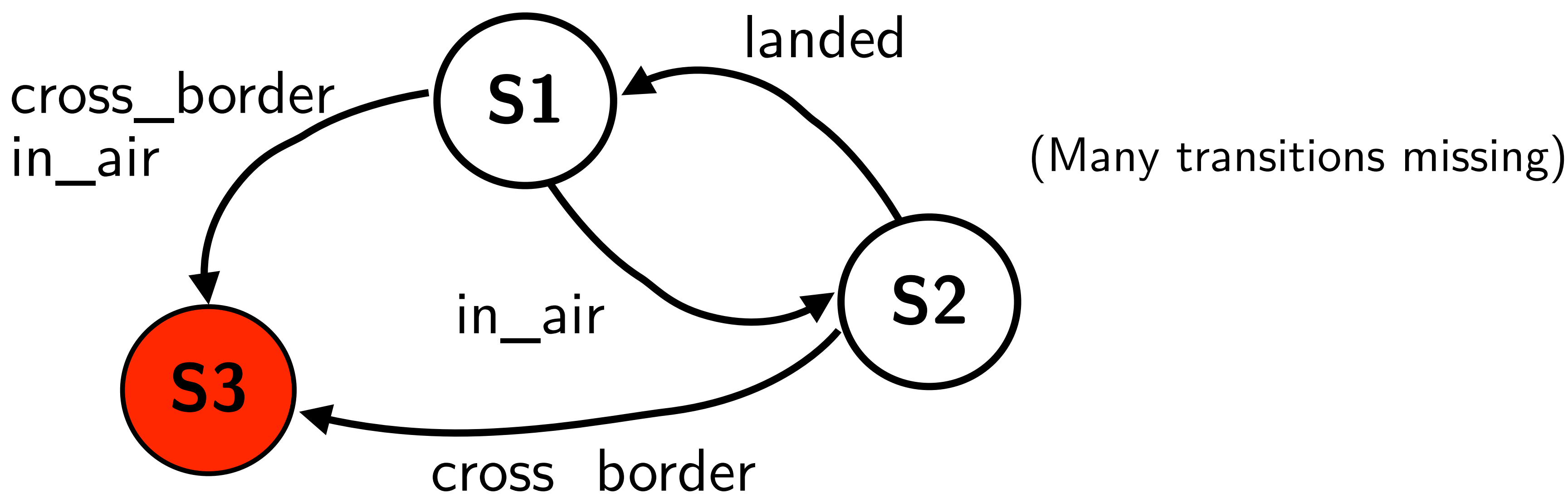
``If we detect that an enemy aircraft has taken off, and if this aircraft crosses our border, an alarm signal should be raised.''

$$\varphi := \mathbf{G}(\mathit{in\_air}(p) \Rightarrow \neg \mathit{cross\_border}(p)\ \mathbf{U}\ \mathit{landed}(p)).$$

- Caveat: no reasoners for temporal descripton logics available

Alert Generation by Runtime Verification

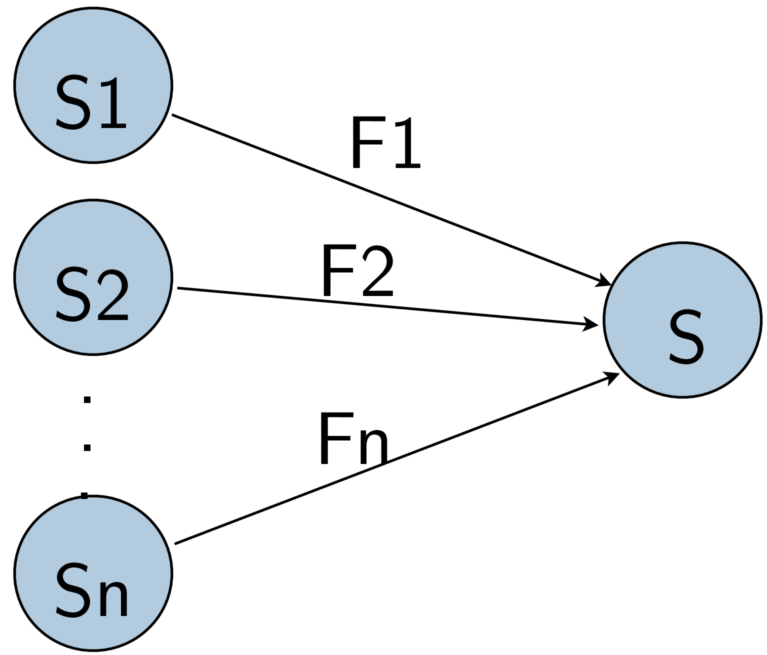
- Operationalization of a LTL formula ϕ in terms of a monitor
- Monitor is a Finite State Machine that reads a finite prefix $u \in \Sigma^*$ and determines if ($w \in \Sigma^\omega$)
  - for all w: $uw \models \phi$ (u is a good prefix), or
  - for all w: $uw \not\models \phi$ (u is a bad prefix)
- Otherwise there exists w, w' such that $uw \models \phi$ and $uw' \not\models \phi$



$$\varphi := \mathbf{G}(\mathit{in\_air}(p) \Rightarrow \neg \mathit{cross\_border}(p)\ \mathbf{U}\ \mathit{landed}(p)).$$

Alerts via Description Logic

FSM monitor: state S
and predecessors



Time: 1 2 . . . j-1 j . . .

$$\bigsqcup_i C_{S_i} \sqcap F_i \Rightarrow C_S$$

For each state S

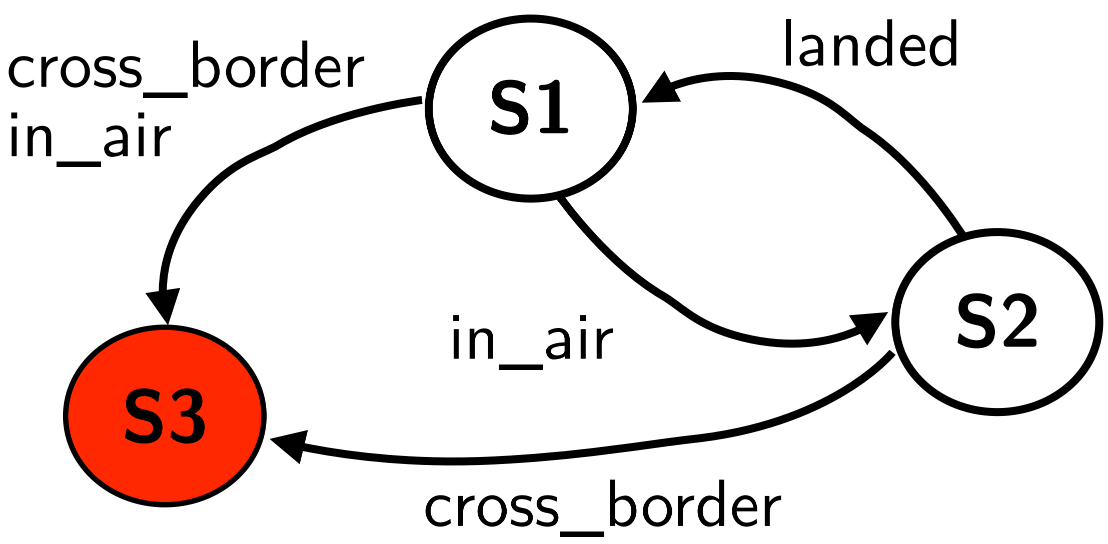
For individuals that satisfy LHS query,
populate concept Cs in the next time point.

Alerts: integration via DL reasoner

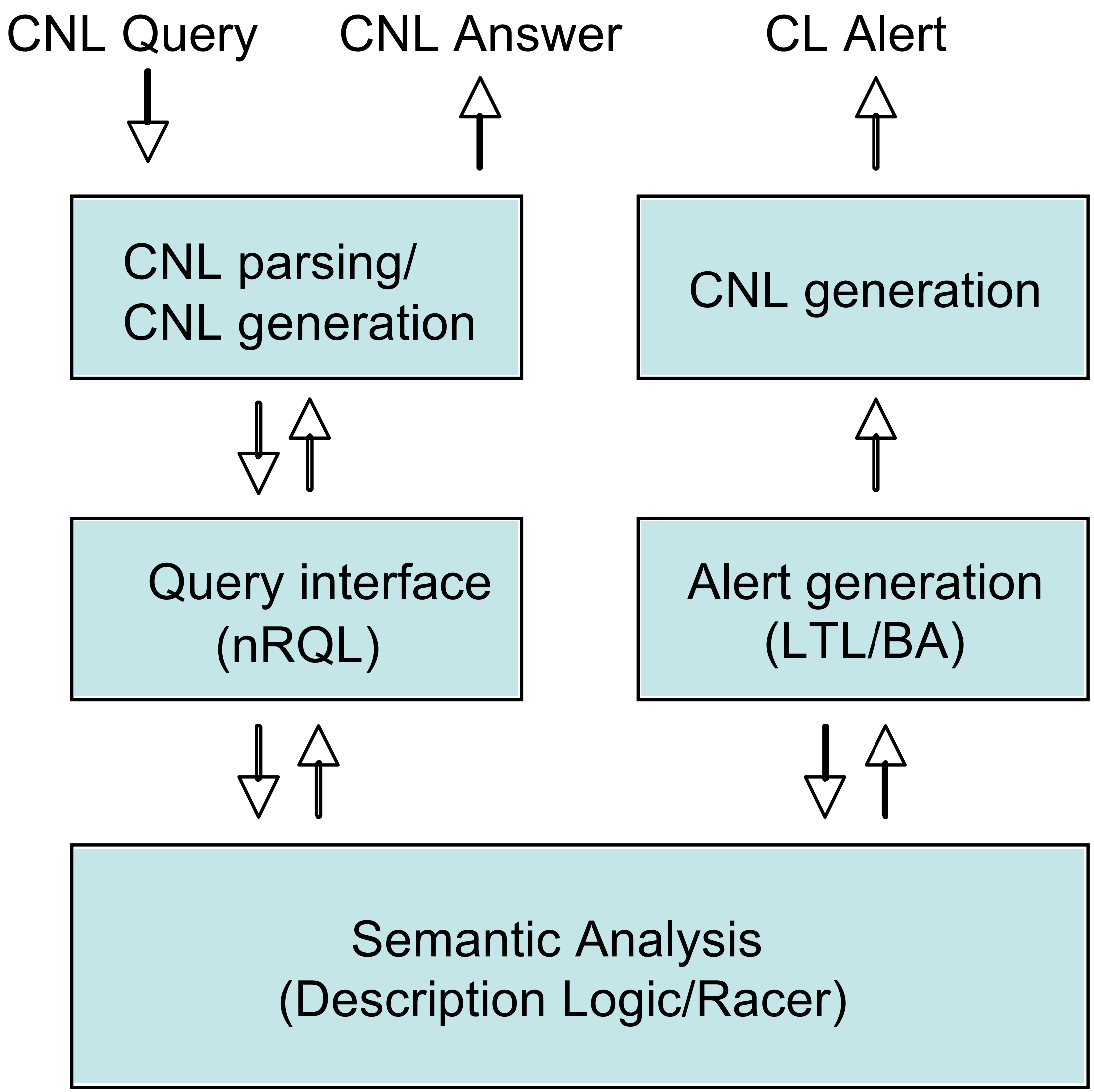
Example: $\varphi := \mathbf{G}(\mathit{in\_air}(p) \Rightarrow \neg \mathit{cross\_border}(p)\ \mathbf{U}\ \mathit{landed}(p)).$

Corresponding concepts/queries for three states:

$$
\begin{aligned}
C_1 : &\quad (C_1 \sqcap \neg \mathit{in\_air}) \sqcup (C_2 \sqcap \mathit{landed}),\\
C_2 : &\quad (C_2 \sqcap \neg \mathit{landed} \sqcap \neg \mathit{cross\_border}) \sqcup (C_1 \sqcap \mathit{in\_air}),\\
C_3 : &\quad C_3 \sqcup (C_1 \sqcap \mathit{cross\_border}) \sqcup (C_2 \sqcap \mathit{cross\_border}).
\end{aligned}
$$



Controlled Natural Language



Controlled Natural Language

- A CNL is an engineered subset of a natural language
  - It looks like English but it is a formal language
- CNL serves as a high-level interface language to SAIL
- Usage:
  - Add eye-witness reports (akin to sensor data)
  - Query the DL knowledge base
- Design of DL knowledge has to be "compatible" with CNL query language
  - events, thematic roles

Controlled Natural Language

- Eye-witness reports

  SU_24M takes off from Becker-Bender at 09:00.
  The A50-1 takes off from Krupali at 09:30.
  The fighter (SU_24M) flies towards Bendeguz.
  The AWACS (A50-1) flies towards Eaglevista.

  are translated into TPTP and then added to the KB
- Anaphora are resolved with the help of the DL ontology

Controlled Natural Language

- Queries

  What aircraft of Redland is able to reach a city of Blueland?

  are translated into conjunctive nRQL queries:

```
(retrieve (?1)
   (and (?1 aircraft)
        (?1 s_redland associated_with)
        (?2 ?1 has_agent)
        (?2 reach)
        (?2 ?3 has_theme)
        (?3 city)
        (?3 s_blueland associated_with)))
```

  and answers are generated in CNL

Conclusions

- SAIL: Layered architecture based on different logical formalisms
  - Tableaux-based answer-set programming (data aggregation)
  - Description logic (semantic analysis)
  - Temporal logic (alert generation)
- System is implemented
  - Tested with excerpts from "Atlantis Scenario"
  - Google Earth interface, GIS system
- Short project runtime of 1 year
  - Work with existing automated reasoning systems
  - Successor project did not happen