Modeling of Resilient Systems in Non-monotonic Logic

Application to Solar Power UAV

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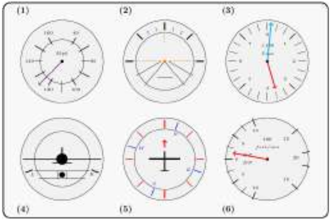
Overview

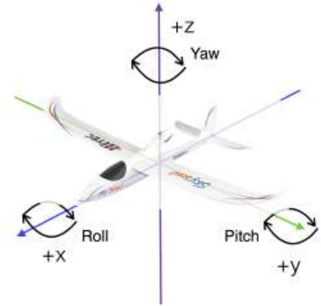
Introduction

- Autonomous motor-glider,
- Different objectives
  - take-off,steady-flight,climb,turn,max. time flight, power management. . .. . .
- Contradiction rules
  - emergency,environment,short time to decide. . .
- Resilient system,
- Decision-Making

Controls

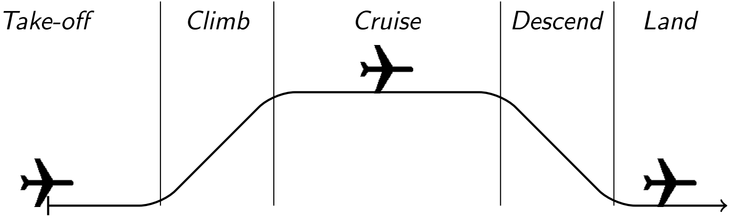


6 Informations : (1)Airspeed, (2) Horizon Artificial, (3) Altimeter, (4) Bank turn, (5) Compass, (6) Variometer

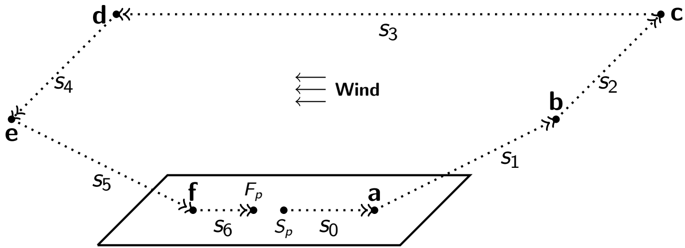


11 Actions :yoke-left, yoke-neutral1, yoke-right, yoke-up, yoke-neutral2, yoke-down, pedal-right, pedal-neutral, pedal-left, max motor, motor off

States flight

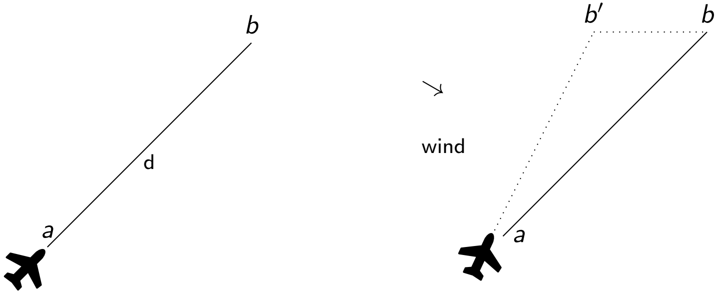


Traffic Pattern



$\{Takeoff, Climb, BankTurn, \ldots, Descend, Final\ \ Approach, Land\}$

Changing objetives



Knowledge Representation

Description in classical logic :

- $alt(down) \wedge var(stable) \rightarrow yoke(pull)$
- $motor(on) \wedge var(up) \rightarrow yoke(push)$
- $alt(high) \wedge var(stable) \rightarrow yoke(push)$
- $motor(on) \wedge alt(down) \rightarrow yoke(pull)$
- $\neg(yoke(push) \wedge yoke(pull))$

Examples

$F = \{alt(down), motor(on), var(up)\}$, we infer $yoke(pull)$ and $yoke(push)$, because of **contradictory actions** it is a contradiction.

Example of exceptions

Rule 91.319

"Operate under VFR[1], day only, unless otherwise authorized"

in classical logic

$VFR \wedge \neg authorized(x) \rightarrow \neg piloting(x)$
$VRF \wedge \neg authorized(x) \wedge \neg day \rightarrow \neg piloting(x)$

Rule 91.7

- "No person may operate an aircraft unless it is in an airworthy condition"
- "Pilot-In-Command is responsible for determining whether that aircraft is in condition for safe flight"

[1]Visual Flight Rules

Example of contradiction

Rule 91

"The minimum over flight height will never be less than 500 feet"[2]

This rule could be expressed in FOL, considering that $x = airplane$:

$$altitude(x) \rightarrow (x \geq 500)$$

But when an airplane lands its altitude is less than 500 feet:

$$land(x) \rightarrow (x < 500)$$

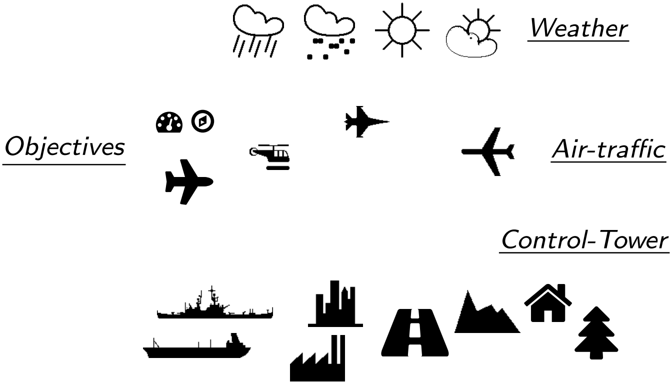
Some more:

$$emergency(x) \rightarrow land(x)$$

$$runway\_obstacle(x) \rightarrow \neg land(x)$$

[2] This altitude depends of the agglomeration.

Real scenario



Overview

Non-monotonic Reasoning

- Monotony:
  - $A \vdash w$, then $A \bigcup B \vdash w$

(The validity of the original conclusion is not changed by the addition of premises)

Example

$$\forall y, aircraft(y) \rightarrow \neg floating(y)$$

But we know that some specials aircrafts float.

$$\forall y, aircraft(y) \wedge floatplane(y) \rightarrow \neg floating(y) \text{ ???}$$

Non-monotonic Logic

McCarthy(Circumscription), Reiter(Default logic), . . .

- New information can invalide previous conclusions,
- Resolve contradictions,
- Reasoning about knowlegde
- Rational conclusions from partial information

Definition

"...we make assumptions about things jumping to the conclusions"

Default Logic [Reiter]

Definition

A default theory is a pair $\Delta = (D, W)$, where D is a set of defaults and W is a set of formulas in FOL.

- A default d is: $\frac{A(X) : B(X)}{C(X)}$
- $A(X), B(X), C(X)$ are well-formed formulas
- $X = (x_1, x_2, x_3, \ldots, x_n)$ is a vector of free variables(non-quantified).

Intuitively a default means, **"if $A(X)$ is true, and there is no evidence that $B(X)$ might be false, then $C(X)$ can be true"**.

With the use of $B(X)$ we get a reorganization of the conclusions as a maximal consistent sets of formulas, called Extensions.

Default Logic [Reiter]

Definition

E is an extension of Δ iff:

- $E = \bigcup_{i=0}^{\infty} E_i$ with:
- $E_0 = W$ and
- for $i > 0$, $E_{i+1} = Th(E_i) \cup \{C(X) \mid \frac{A(X):B(X)}{C(X)} \in D,$ $A(X) \in E_i \wedge \neg B(X) \notin E\}$

Property

If every default of D is normal : $\frac{A(X):B(X)}{B(X)}$

$\neg B \notin E$ is replaced by $\neg C \notin E_i$

If W is consistent, there is always extensions and greedy algorithm

Example

$$d_1 = \frac{((altitude(x) \geq 500) \wedge roll(x, stable)) : steady\_flight(x)}{steady\_flight(x)}$$

$$d_2 = \frac{((altitude(x) < 500) \wedge roll(x, stable)) : land(x)}{land(x)}$$

$$d_3 = \frac{(land(x) \wedge obstacle) : climb(x)}{climb(x)}$$

Assuming the following information :

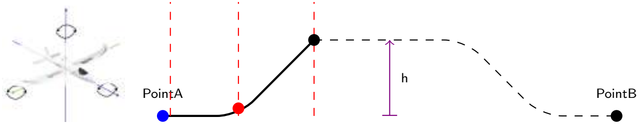
$$W = \{(alt(x) \leq 500), roll(x, stable), obstacle\}$$

From $\Delta = (D, W)$, we calculate the set of extensions.

- $E_1 = W \cup land(x)$
- $E_2 = W \cup climb(x)$

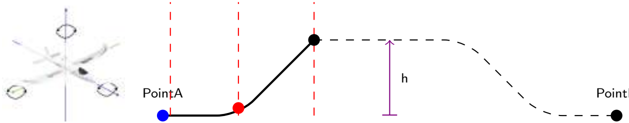
Simulation

$$W : \{glider(pitch\_stable), glider(roll\_stable), \neg glider(motor\_on),$$
$$glider(low\_altitude), glider(low\_airspeed)\},$$
$$D : \{d_1, d_2, d_3, \ldots, d_{50}\}, \left(d_i = \frac{A(X):B(X)}{B(X)}\right)$$



Simulation

Solutions	Actions		
E_0	*yoke_roll(neutral)*	*yoke_pitch(neutral)*	*motor(on)* ←
E_1	*yoke_roll(neutral)*	*yoke_pitch(neutral)*	*motor(off)*
E_2	*yoke_roll(neutral)*	*yoke(push)*	*motor(off)*
E_3	*yoke_pitch(neutral)*	*yoke(pull)*	*motor(on)* ←
E_4	*yoke_pitch(neutral)*	*yoke(pull)*	*motor(off)*



Which extension to choose?

Decision-Making

- In decision theory, there is a opportunistic model,
- For each default (d) there is a weighting (p),
- Criterias such as legislation, risk, energy, ...

Definition

$$\forall E, min \left\{max\left(c_i\right) - c_j\right\}$$

Where c_i is the value of the criteria and c_j are the alternatives.

Decision-Making

For $E_n = \{d_2, d_3, d_4\}$

Score				
Very low	Low	Medium	High	Very high
0	1	2	3	4

Alternatives	C_1	C_2	C_3
d_2	1	0	1
d_3	4	2	4
d_4	3	2	3

Alternatives	C_1	C_2	C_3	**Decision**
d_2	3	2	3	3
d_3	0	0	0	**0**
d_4	1	0	1	1

Decision-Making

Alternatives	**D**		
E_1	d_3	d_7	d_{18}
E_5	d_2	d_5	d_{10}
E_{17}	d_7	d_{14}	d_{20}

The set of solutions :
$E_n = \{[x_{d1}, y_{d1}, z_{d1}], [x_{d2}, y_{d2}, z_{d2}], [x_{d3}, y_{d3}, z_{d3}], \cdots\}$

$$\frac{C1_n}{x_{d1}} + \frac{C2_n}{x_{d2}} + \frac{C3_n}{x_{d3}} + \cdots \in |C1_n|$$
$$\frac{C1_n}{y_{d1}} + \frac{C2_n}{y_{d2}} + \frac{C3_n}{y_{d3}} + \cdots \in |C2_n|$$
$$\frac{C1_n}{z_{d1}} + \frac{C2_n}{z_{d2}} + \frac{C3_n}{z_{d3}} + \cdots \in |C3_n|$$
$$\vdots$$

Decision-Making

Each E is associed with a set of ponderations:

$$E_n = \{|C1_n|, |C2_n|, |C3_n|, \cdots\},$$
$$E_{n-1} = \{|C1_{n-1}|, |C2_{n-1}|, |C3_{n-1}|, \cdots\},$$
$$E_{n-2} = \{|C1_{n-2}|, |C2_{n-2}|, |C3_{n-2}|, \cdots\} \ldots$$

Ext-Crit	$C1$	$C2$	$C3$	$\cdots$
E_n	X_n	Y_n	Z_n	$\cdots$
E_{n-1}	X_{n-1}	Y_{n-1}	Z_{n-1}	$\cdots$
E_{n-2}	X_{n-2}	Y_{n-2}	Z_{n-2}	$\cdots$
$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\ddots$

Applying "a posteriori" decision-making, we find E_n.

Overview

Definition

In Ecology:

The property of a system to absorb and anticipate perturbations [Holling].

In Psychology:

An ability to successfully survive with adversity [APA][3].

In Engineering:

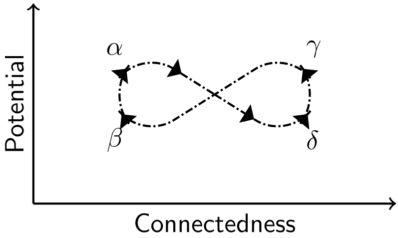
It ensures robustness and stability [Goerger, S.].

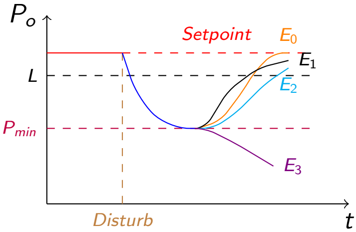
[3] American Psychological Association

Holling's Definition

The flow of events:

Exploration (β), *Reorganization* (α), *Conservation* (δ) and *Release* (γ).





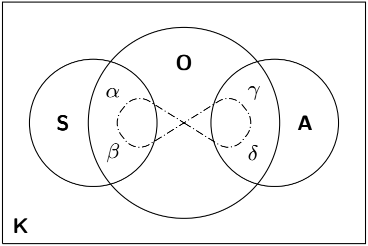
Intuitively, the computation of Extensions corresponds to β, Decision-Making corresponds to α and δ, and interactions with environment is γ.

Non-monotonic Model

Theorem

In the world **K**, there is always a resilience trajectory $R : \{\alpha, \beta, \gamma, \delta\}$.
Where **S** are situations, **O** are objectives and **A** are actions.

$$\forall S, \forall O, \forall A \subseteq K \; \exists \; R$$



Short and Long term Objectives

Short-term

When an airplane is placed at the start point (S_p), assuming it has the authorization, and it is possible to take-off, then the plane take-off.

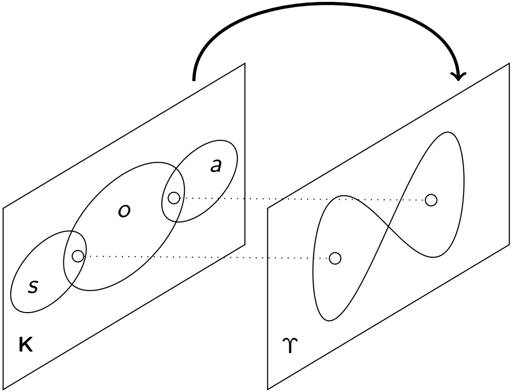
$$\frac{(rest(x) \wedge authorization) : takeoff(x)}{takeoff(x)}$$

Long-term

When a plane (starts at some point a) wants to maintain an altitude greater than 1500 feet and a north direction, to reach to the point b

$$\frac{((alt(x) > 1500) \wedge compass(x, north)) : point(x, b)}{point(x, b)}$$

Dynamics of Non-monotonic Resilience: Tentative Representation



Fonction of choice: $\Upsilon(f) : S \cap O \rightarrow O \cap A$

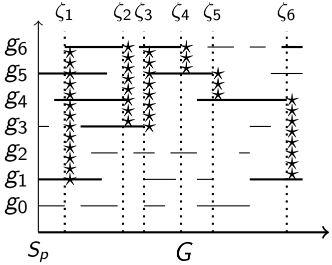
Discrete Non-monotonic Resilience Model

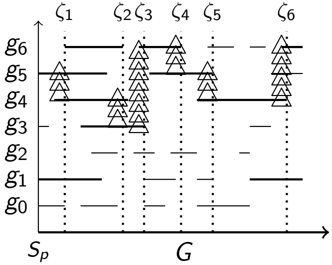
Definition:

The convergence of an objective G is the sum of the product of the sub-objectives g and disturbances ζ.

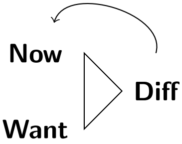
$$\bigcup_{i=0}^{\infty} G_i = \bigcup_{i=0}^{\infty} g_i \cdot \zeta_i$$

$R_\star = \{g_1, \zeta_1, g_6, \zeta_2, g_3, \zeta_3, g_6, \zeta_4, g_5, \zeta_5, g_4, \zeta_6, g_1, \ldots\}$(left)
$R_\triangle = \{g_5, \zeta_1, g_4, \zeta_2, g_3, \zeta_3, g_6, \zeta_4, g_5, \zeta_5, g_4, \zeta_6, g_6, \ldots\}$(right)

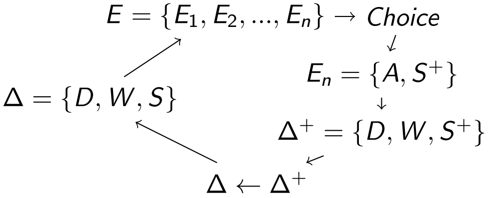




Minsky's Model



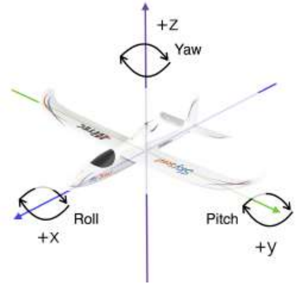
(a) Minsky's model

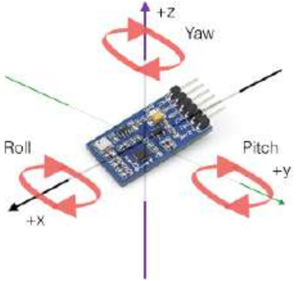


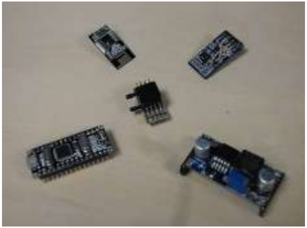
(b) Non-monotonic Resilience Model

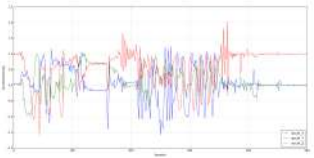
Overview

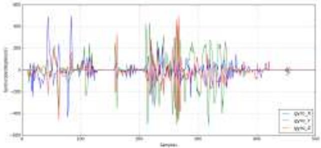
Practical Case

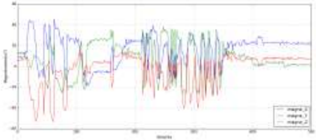


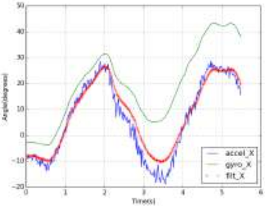












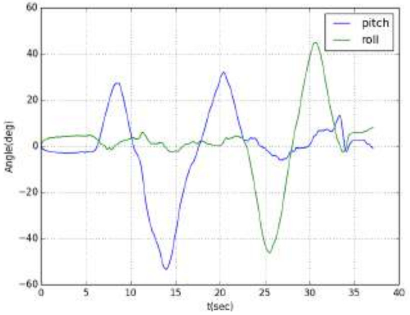
Complementary filter

$$angle_i = 0.98 * (angle_{i-1} + gyro * dt) + 0.02 * (acc)$$

Results

Facts	Extensions	Instanced clauses	CPU	Lips
7	13	115	95%	114,131
5	13	113	98%	117,176
4	10	112	97%	130,098

Movie



Overview

Conclusion

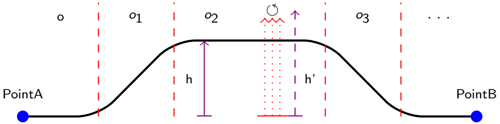
- Simulation of piloting behaviour,
- We tackled contradictory and incomplete information,
- Resilient model based on default logic,
- Logical approach of resilience, linked with the mathematical notions,
- Non-monotonic model in a embedded microcomputer, cpu running at 1 GHz ARM11 (single core), 512 Mb of RAM and power consummation of 0.8 Watts,
- Until now we have 100 defaults. Extensions are computed in milliseconds.

Papers

- Autonomous Aerial Vehicle: Based on Non-Monotonic Logic, VEHITS'17
- Contrôle de Vol d'un Planeur Basé sur une Logique Non-monotone, APIA'17
- Non-monotonie et Resilience: Application au Pilotage d'un Moto-planeur Autonome, JIAF'18
- Intelligent and Adaptive System based on a Non-monotonic Logic for an Autonomous Motor-glider, ICARCV'18

Perspectives

- Autonomous in electrical energy (solar panel),
- Finding natural sources of energy (ascending winds, . . .),
- Other applications (driving behaviour, control systems, . . .)



Merci pour votre attention.