Toward Human-Machine Cooperation

Keynote lecture

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How to integrate the Human Operator(s) into systems not-fully automated

For which classes of activities ?

- Continuous Control Tasks (vehicle driving)

- Discontinuous supervision tasks : (large production or transport systems)

    - fault detection

    - trouble shooting

        . diagnosis/prognosis

        . decision making

        . recovering action

        . following the action

-Arguments against the human integration

- Bounded human capabilities (precision, power)

- Inter and intra-individual human variations
  (uncertainty of the prediction of their behaviour)

-Arguments in favour of the human integration

- Bounded decision capabilities of the automated systems :
  . perception, decision making and control capabilities of the machine remain limited
  . loss of « imagination » of the machine

-Technocentered Pathway

→ Human beings are not welcome … but needed
→ Their roles are defined by default :
  - activities too complex to be automated
  - without taking the human capabilities for these activities into account
→ That could result in human errors

Anthropocentered Pathway

- Model of Human Operators seen as system :

. control system (Johannsen, Govindaraj 80, Baron 68, 82)

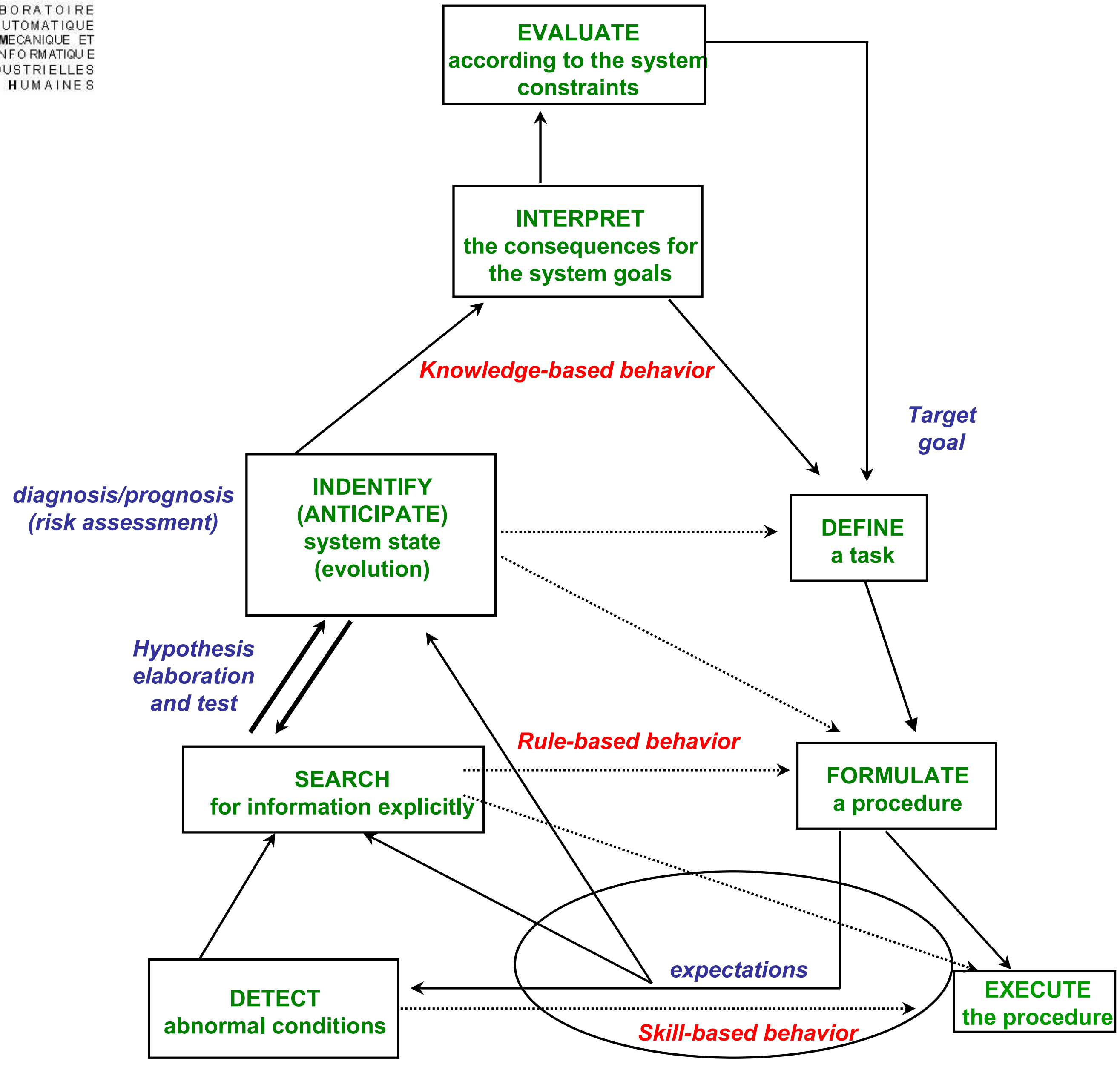
. decision maker (Rasmussen 83, Millot 88, Hoc 96)

- Identify their intrinsic capabilities and limits

- Define variables related to the human activity, human limits and capabilities , Foresse experimental measurements : workload, performance (Millot 88)

- Sharing the tasks to be performed between Human beings and Machines according to a double criterion (Millot 99) :

  - 1st task-sharing according to a criterion of technical feasibility
  - 2nd task-sharing according to a criterion of human feasibility



Rasmussen’s step-ladder revisited (after Hoc 96)

Anthropocentered Pathway

- Model of Human Operators seen as system :
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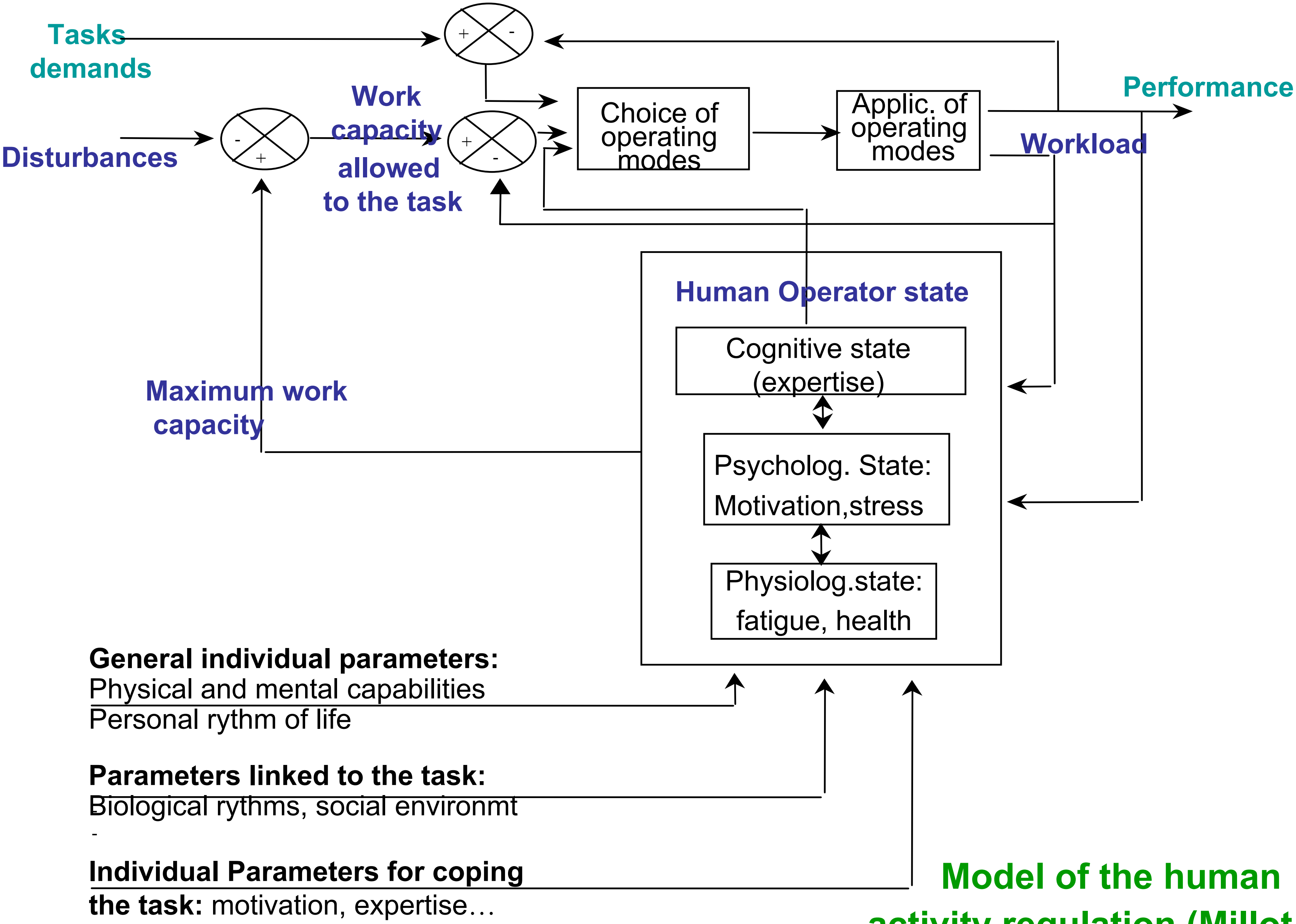

Model of the human activity regulation (Millot,03)

Anthropocentered Pathway

- Model of Human Operators seen as system :

  . control system (Johannsen, Govindaraj 80, Baron 68, 82)

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- **Sharing the tasks to be performed between Human beings and Machines according to a double criterion (Millot 99) :**

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  - 2nd task-sharing according to a criterion of human feasibility

Sharing the tasks between Human and Machine

Defining the automation degree of the overal system :

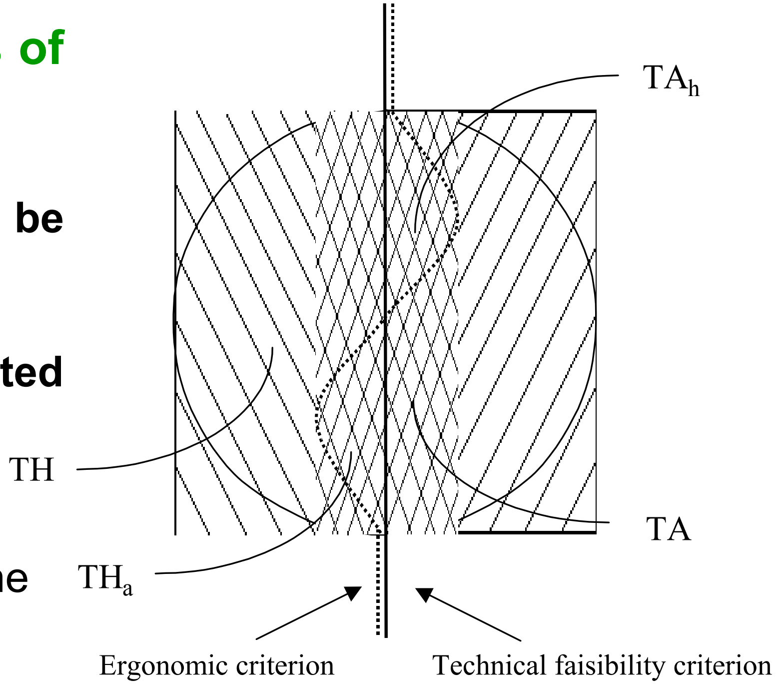
T = set of the tasks to be performed

TA = set of the tasks which can be automated | according to the criterion
TH = set of the tasks which cannot be automated | of Technical feasibility

The ergonomic criterion creates 2 new classes of tasks :

TA_h = Tasks which can be automated but to be allocated to the HO
(skill, responsability…)
TH_a= not fully automated tasks but partially automated for assisting HO
(ex : ABS, diagnosis).

These classes can be used for defining a Human-Machine Cooperation.



Task Sharing/Cooperation

-Characteristics of Control-Tasks :

- Dynamic task allocation of the DOF of a Remote Control Arm
- Dynamic task allocation of the DOF of an automobile (lateral control, Automated Cruise Control…)
- « Skill Based Behaviour » in Rasmussen's ladder

- Very short response time (<1 second) the allocation must be imposed by an upper control system to both controllers human and machine.

- Once decided the allocation cannot be changed.

- Characteristics of Decision tasks :

- Longer response time (several minutes) : the tasks allocation can be cooperatively decided by both decision-makers human and machine.

Questions :

How to do this ? What capabilities must be integrated in the machine for doing so ?

A Definition of Cooperation
(HOC, 96 ; MILLOT, HOC, 97)

Two agents **cooperate** when :

1. they **manage the interferences** between their goals (MI ≈ coordination)

2. each agent acts in order **to facilitate** the other agent's goals (FG = Facilitating Goals)

An agent AGi has :

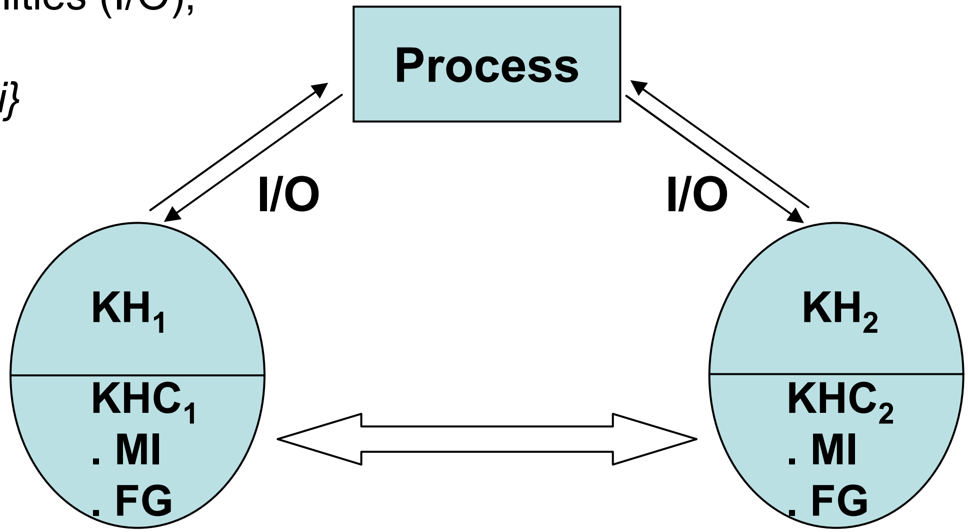
*. A **Know-How** (KHi)*

Knowledge, Reasonning capabilities,
Communication capabilities (I/O),

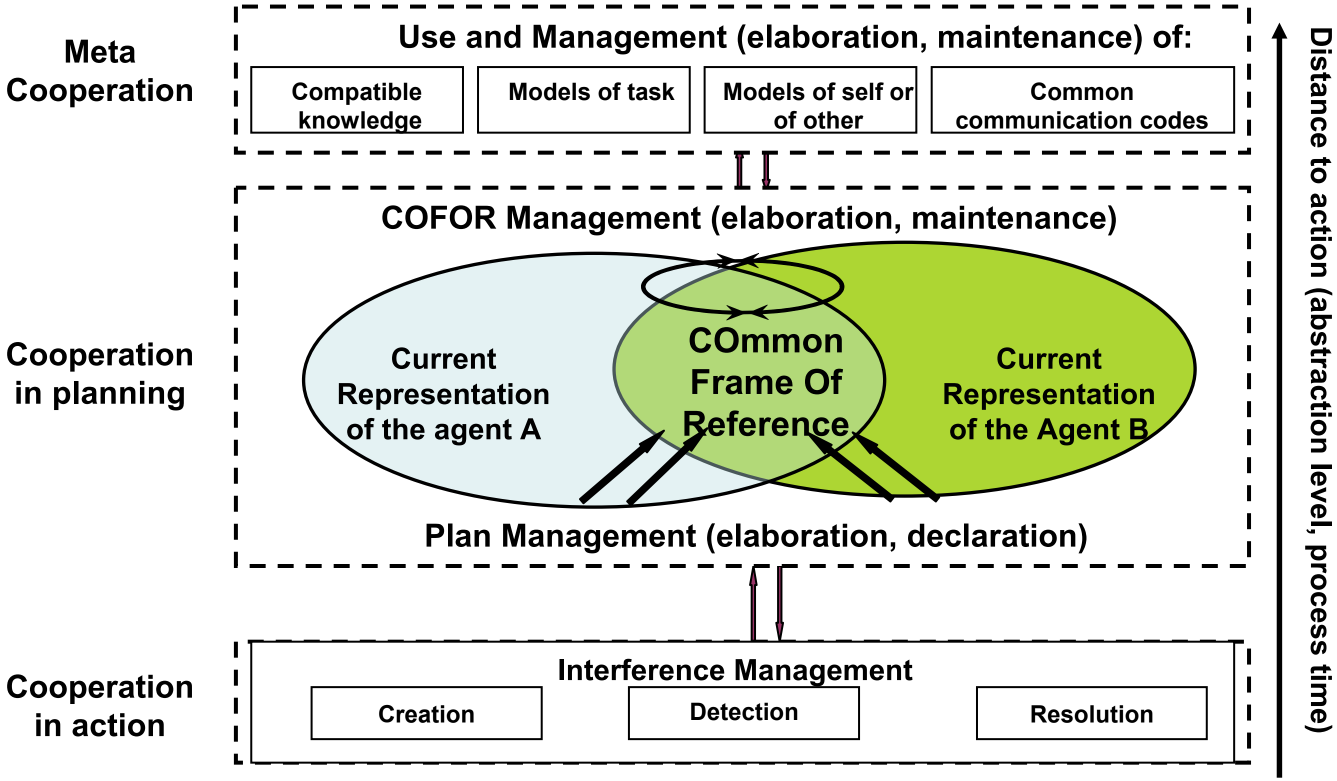
*. A **Know-How to Cooperate** KHCi = {MIi, FGi}*

Questions :

. Which **functions** for KHC ?
. What **structure** for connecting the agent together and to the environnement (I/O with the process,the rest of the world) ?



Cooperation Architecture
Hoc (2000, 2001) et Loiselet (Hélie & Loiselet, 2000)



Specifying the functions of the agent KHC, following 3 steps :

1. **Defining these functions through the 3 cooperation forms defined by Schmidt (91)**

   - Augmentative :
   . Agents have **similar KH_i**
   . The task T can be **shared into ST_j independant and similar**

   - Debative :
   . Agents have **similar KH_i**
   . T **is not shareable**

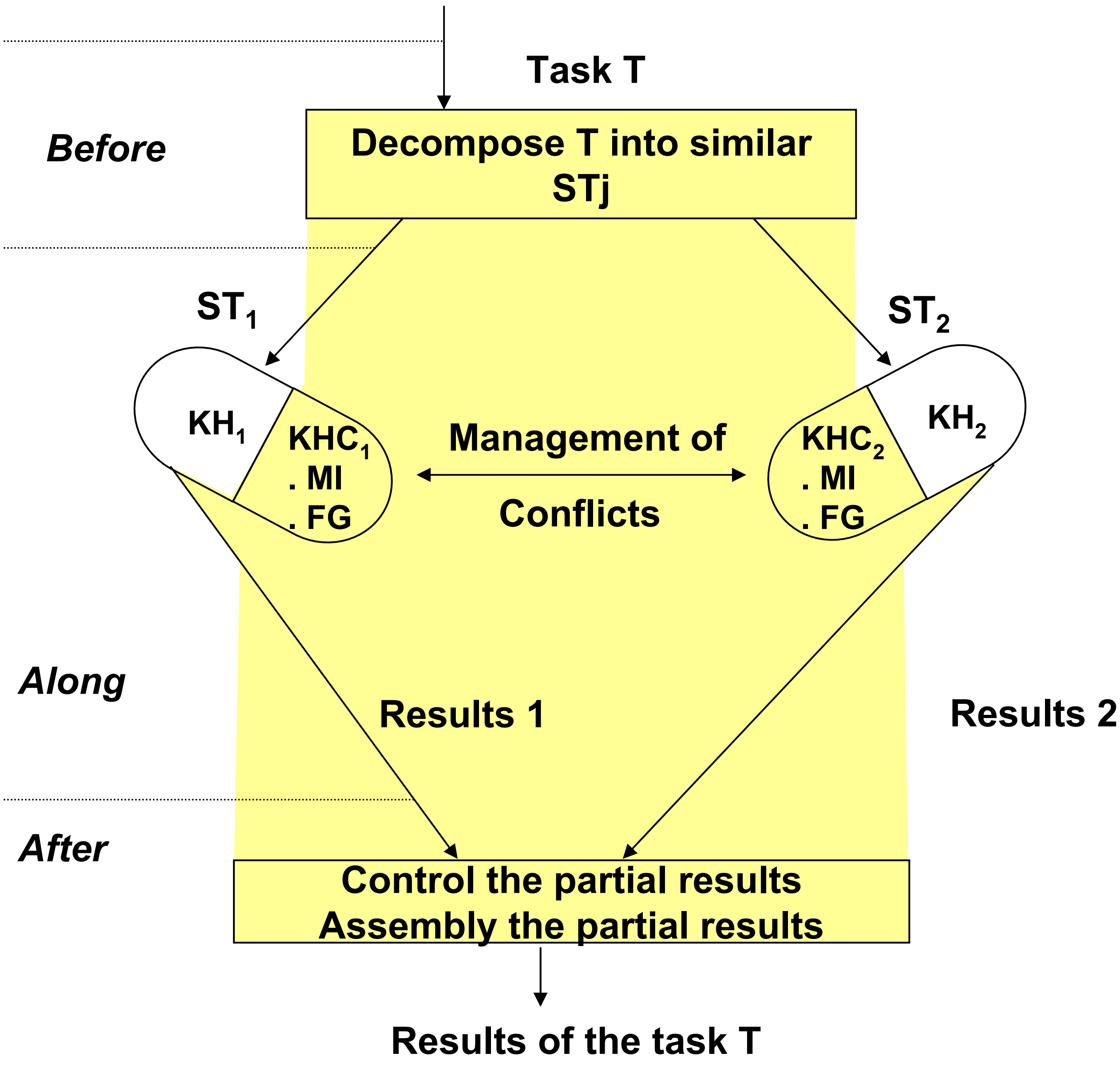
   - Integrative :
   . Agents **have different and complementary KH_i**
   . T is **shareable into ST_j different and complementary**

2. **Showing these 3 forms are generic of all kinds of cooperation (Base)**

3. **Then the general function of a general cooperative agent could be built by adding the cooperative functions of each form :**

$$KHCi = KHCi_A \cup KHCi_D \cup KHCi_I$$

Augmentative Cooperation Form



AGi with
Similar KHi

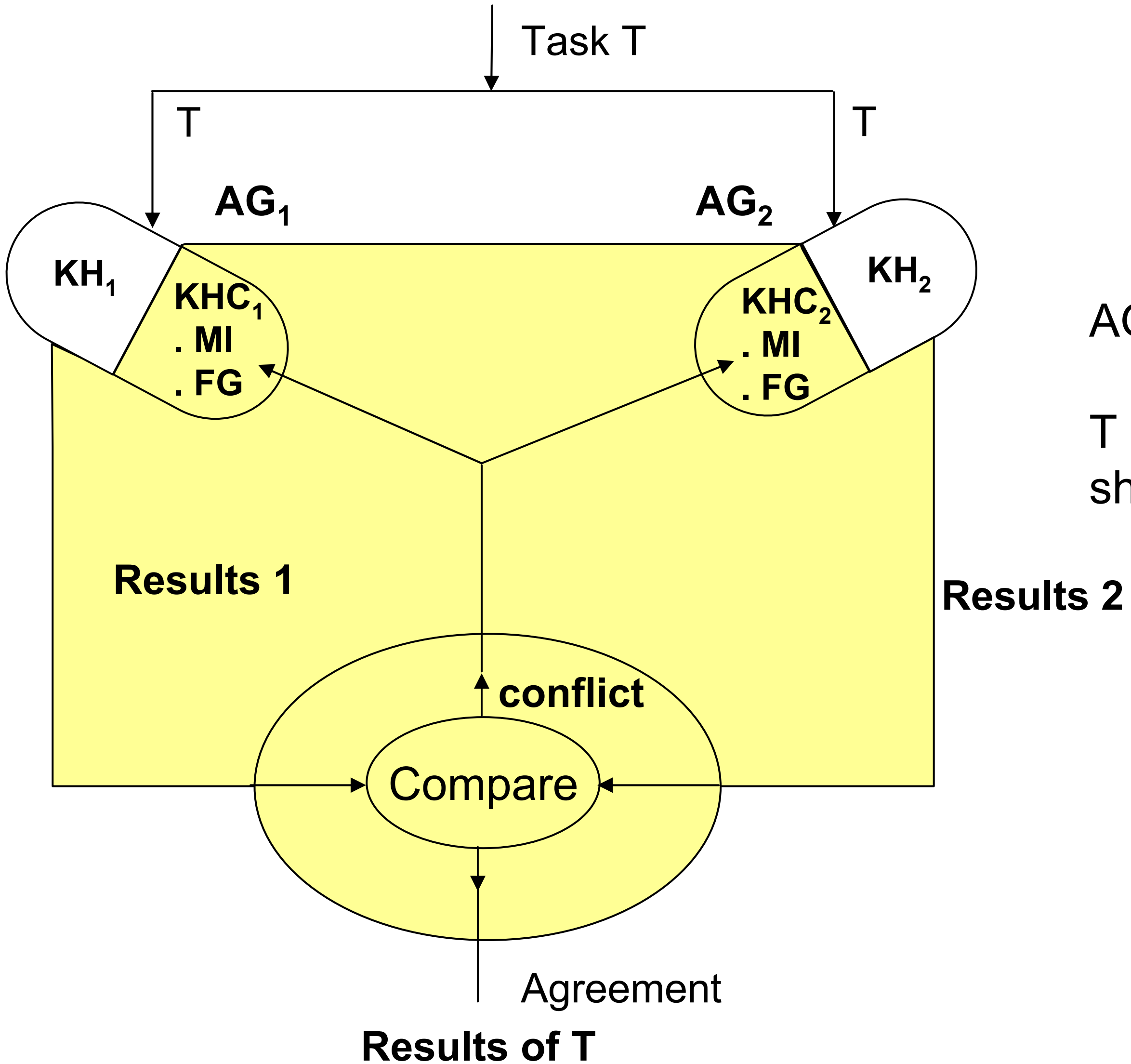
T shareable into STj
Independant and
similar

Results 2

Activities		Coordinator	AGx (vs AGy)
		KH: Task Context, -Defining a COFOR (from inference, from the passed experience) -Elaborating a global plan, decomposing the plan	KHx (vs KHy) : -answering the coordinator for building the COFOR -executing the sub-plan related to its own STi -detecting conflicts on resource with AGy (vs AGx)
Before	Decomposing T into STi	KHC MI : acquiring KHx and KHy	FG : transmitting its KHx (vs KHy)
	Allocating STi	MI : -acquiring WLx and WLy -allocating STi to AGx (vs AGy)	FG : -transmitting its WLx (vs WLx) -acknowledgement of its intention to perform STi
Allong	Managing conflicts between AGx and AGy on common resources	MI : -acquiring conflict signal from AGx or AGy -affecting priority to AGx (or AGy) -affecting resource to the other afterwards	FG : -informing coordinator on the occurrence of conflict -informing coordinator that the ressource is available
After	Recomposing/controlling the results	MI : -acquiring results (contexts) from AGx and AGy -controlling results (contexts) form AGx et AGy	FG : -transmitting results (context) to coordinator -transmitting sub-plan (sub-goal) to coordinator

Table 1 : Summary of KHC activities (MI, FG) of the agents in an augmentative cooperation

Debative Cooperation form

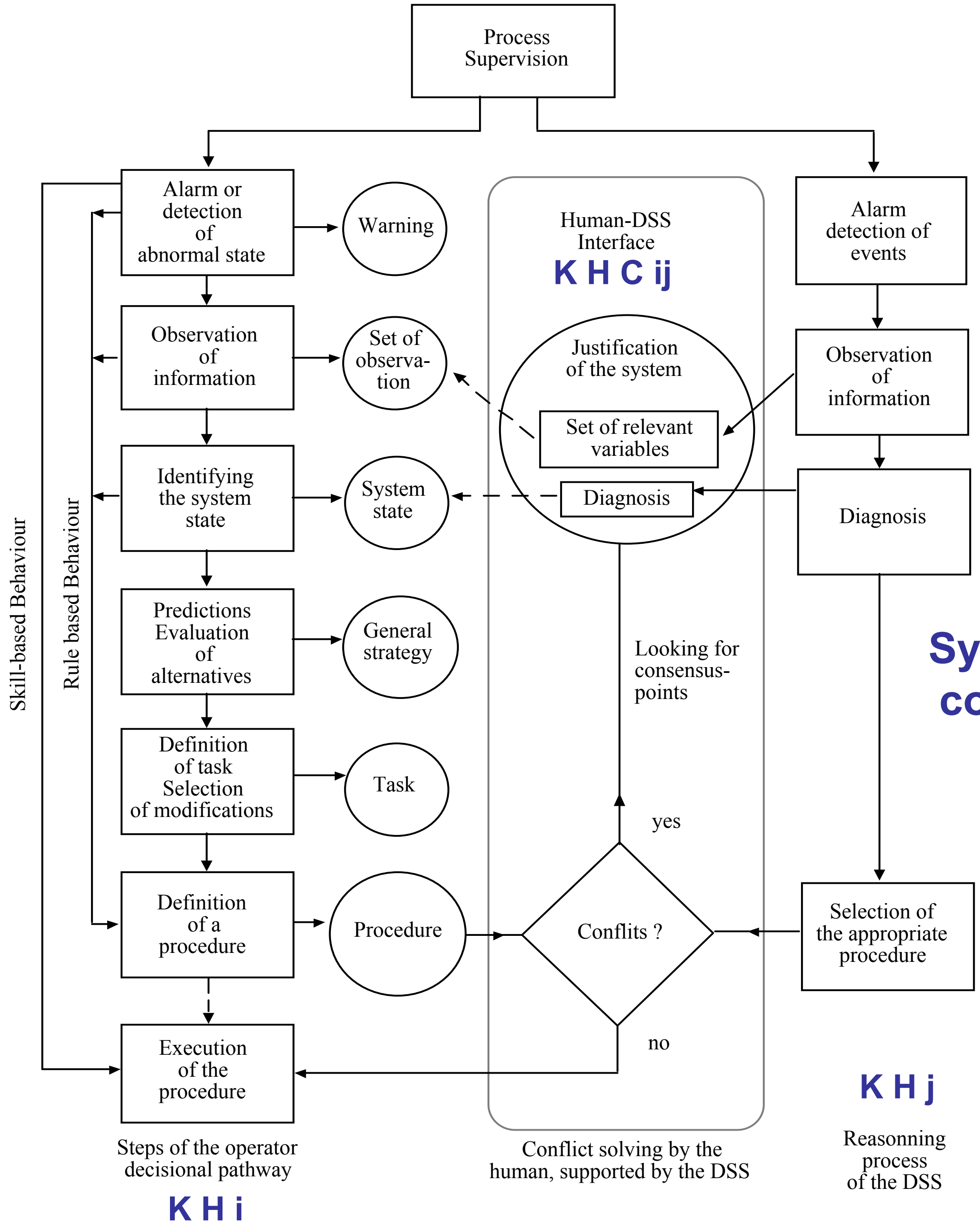


AGi with similar SFi

T unique and non shareable

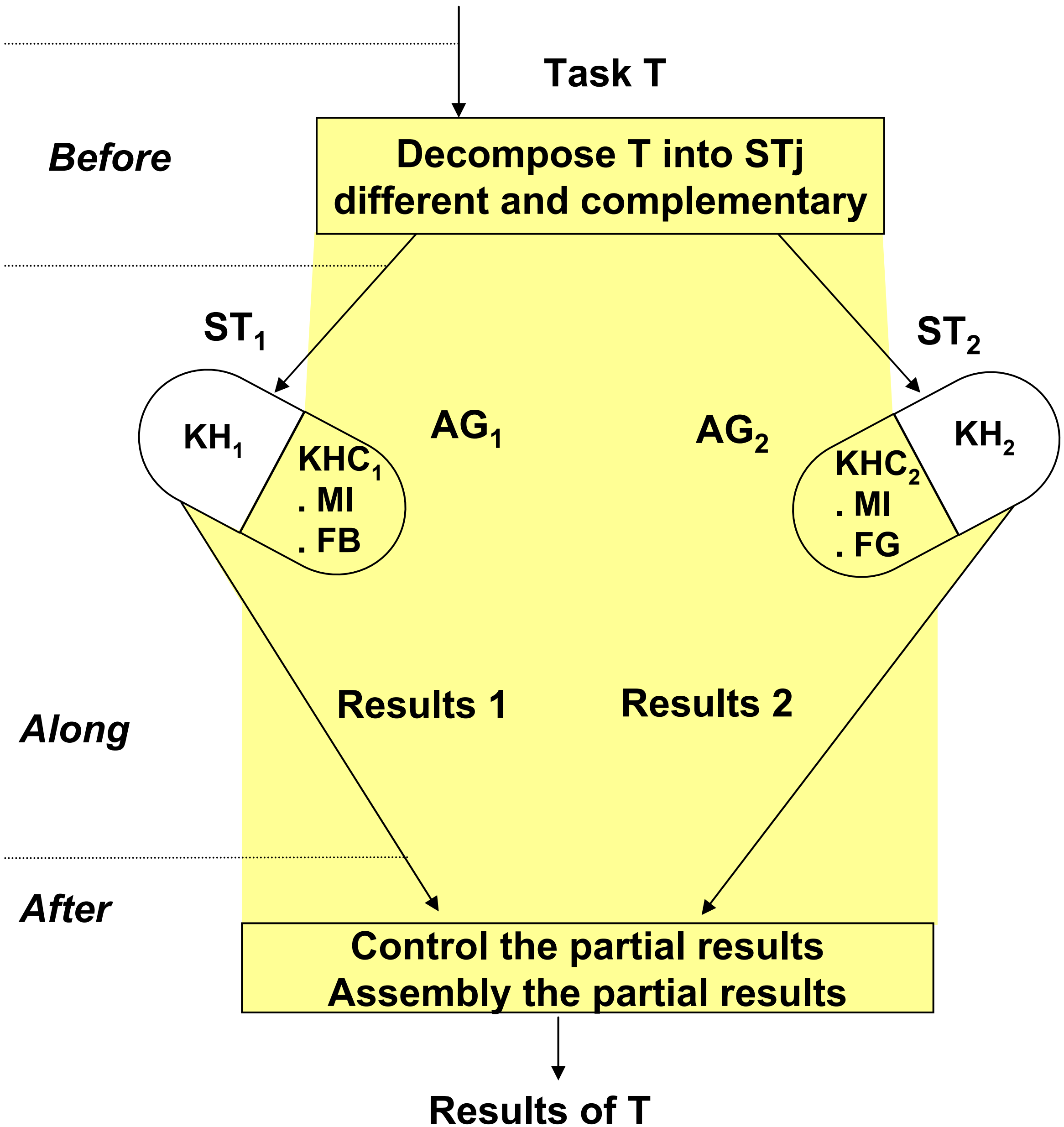
Activities	AGx (vs AGy)
	KH : task context -Defining a COFOR (from inference, from the passed experience) -elaborating a plan
Preparing cooperation	KHC : MI : acquiring (infering) KHx (vs KHx) FG : transmitting its KH to the other
Comparing results (even partial)	KHC : MI : acquiring results from AGy (vs AGx) FG : transmitting results to AGx (vs AGy) MI : -understanding results from AGy (vs AGx) -comparing with its own results, -deciding : agree, desagree
Conflict solving	KHC : MI : acquiring AGy's (vs AGx) plan and view-point on task context FG : transmitting its own plan and view on the context to the other MI : -comparing both contexts and plans -deciding on the conflict persistance FG : accepting its own error and drawing the lesson

Table 2 : Summary of the KHC activities of the agents (MI, FG) in a debative cooperation



Synthesis of the decisional conflict pathway between the HO and the DSS

Integrative Cooperation Form



AGi with SFi
. different
. Complementary

T shareable into STj
. different
. complementary

Activities		Coordinator	AGx (vs AGy)
		KH : Task Context, -Defining a COFOR (from inference, from the passed experience) -Elaborating a global shared plan, -Decomposing the global plan into sub-plans (STi)	KHx (vs KHy) : -answering the coordinator for building the COFOR -executing the sub-plan related to its own Sti -correcting its STi if required by the coordinator
Before	Decomposing T into STi	KHC : MI : acquiring (infering) KHx and KHy	KHC : FG : transmitting its KHx (Vs KHy)
	Allocating STi	MI : -acquiring WLx and WLy -allocating STi to AGx (vs AGy)	FG : -transmitting its WLx (vs WLy) -acknowledgement of its intention to perform STi
Allong	Controlling partial results	MI : -acquiring partial results (context) -comparing results to plan and to sub-plans -ordering corrections to AGx or AGy if needed	FG : -transmitting (partial/results context) to coordinator -correcting the STi if asked by the coordinator
After	Recomposing/Controlling the results	MI : -acquiring results (context) -controlling results (context) -ordering corrections to AGx or AGy if needed	FG : -transmitting results (context) to coordinator -correcting the STi if asked by the coordinator

Table 3 : Summary of the KHC activities (MI, FG) of the agents in an integrative cooperation : Case of a shared plan elaborated by a coordinator

Genericity of the 3 cooperation forms by Schmidt

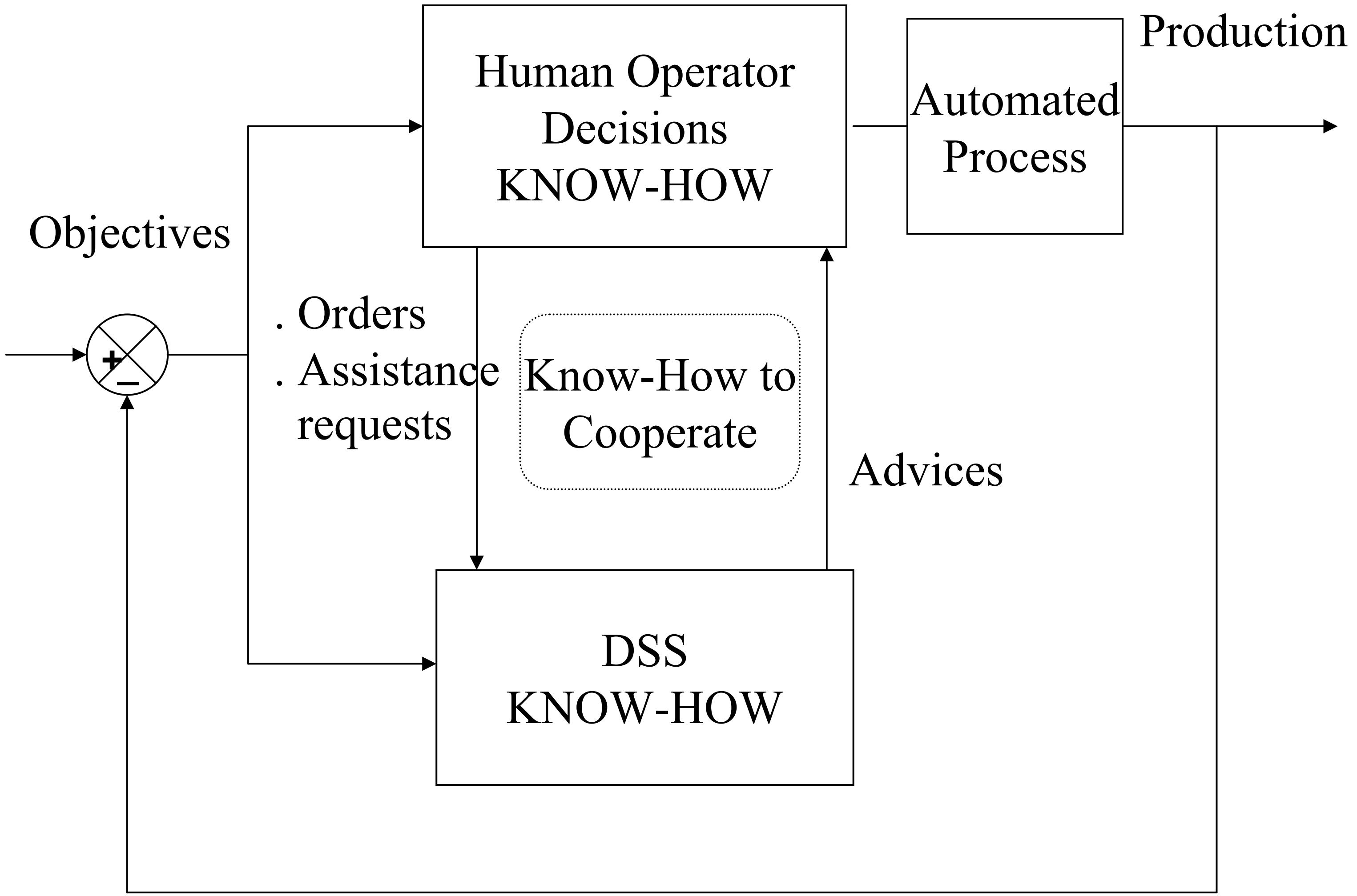
2 agents AGi (KHi, KHCi)

1 task T

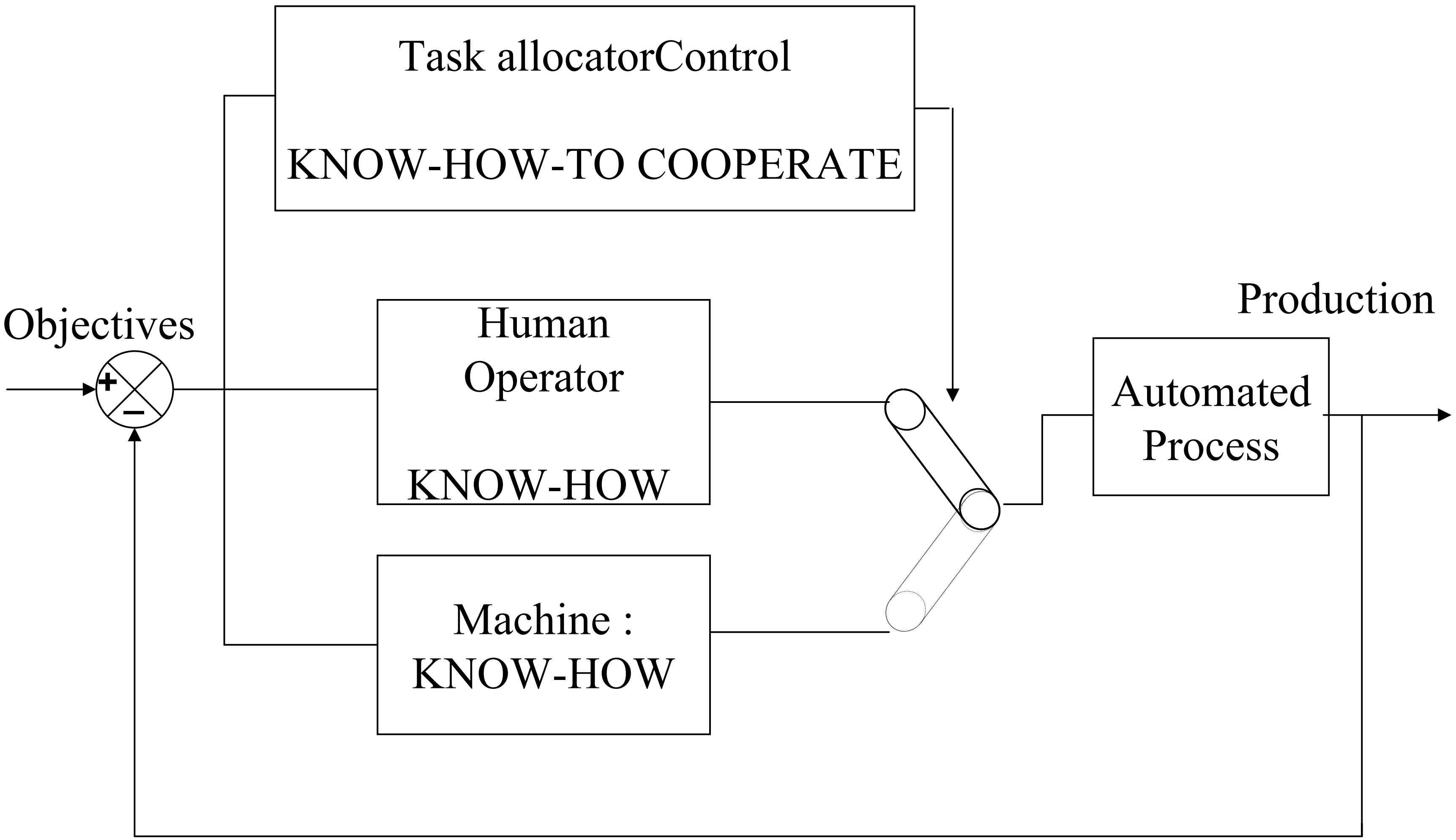
		Similar KHi	Different KHi
Shareable Tasks	Similar STj	Augmentative	Cooperation impossible
	Different STj	Cooperation impossible	Integrative
Non-shareable Tasks		Debative	Cooperation impossible

All kind of cooperation is a combination of the 3 cooperation forms by Schmidt

Adequacy of Agi / Task shareability		Similar KHi	Different KHi
Shareable Tasks	Similar STj	Augmentative	Cooperation impossible
	Different STj	Cooperation impossible	Integrative
Non-shareable Tasks		Debative	Cooperation impossible



Vertical structure for a H-M Cooperation



Horizontal structure for a H-M Cooperation

These 3 forms have been implemented and tested in several applications

- Diagnosis support system for a telephone network
  (Jouglet, Vanderhaegen, Millot, 01).

- Dynamic Task Allocation between Human and DSS in the ATC domain
  . Augmentative form (Debernard, Vanderhaegen, Millot 1993)
  . Multi-form (Guiost, Debernard 2004)

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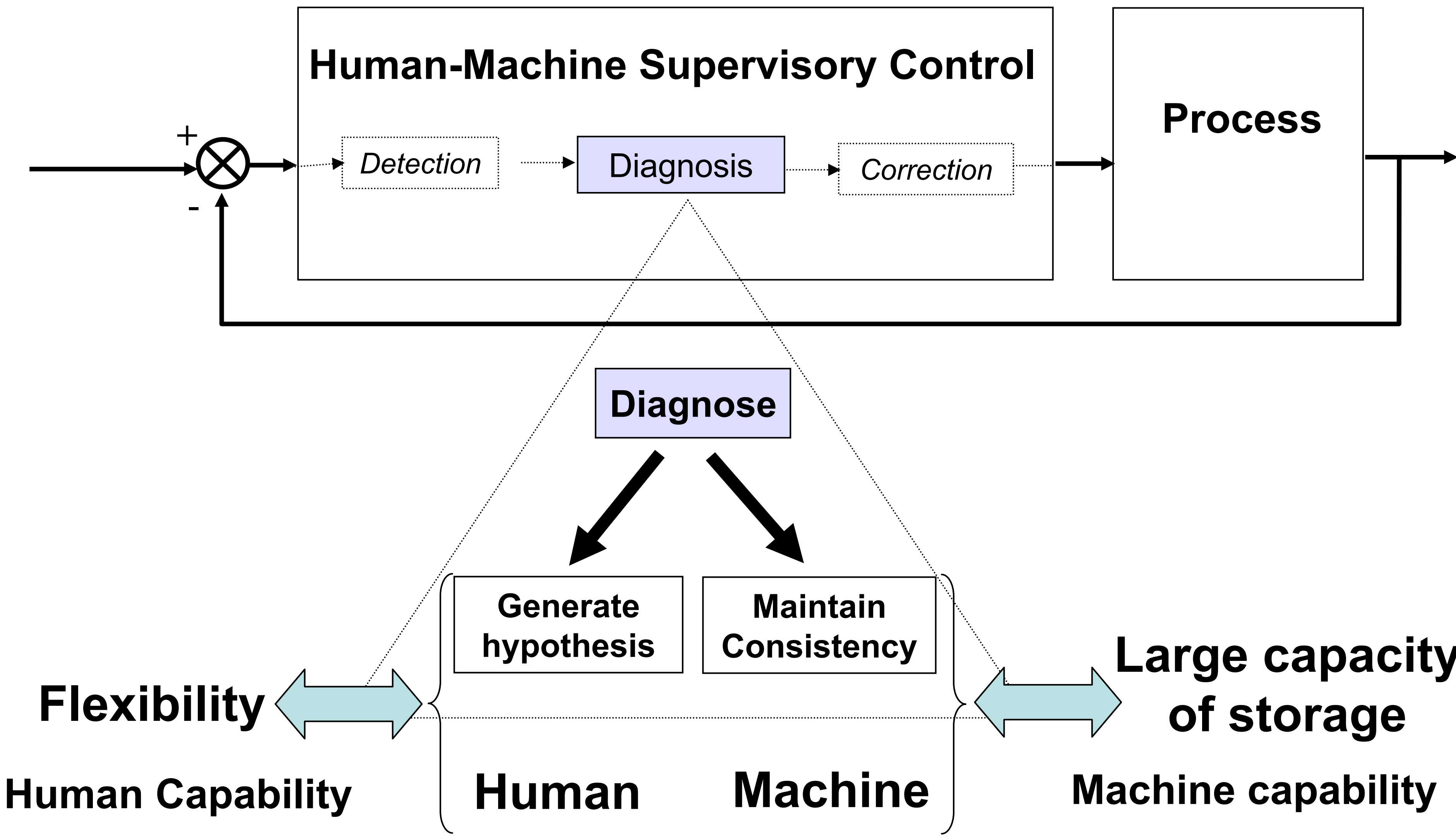
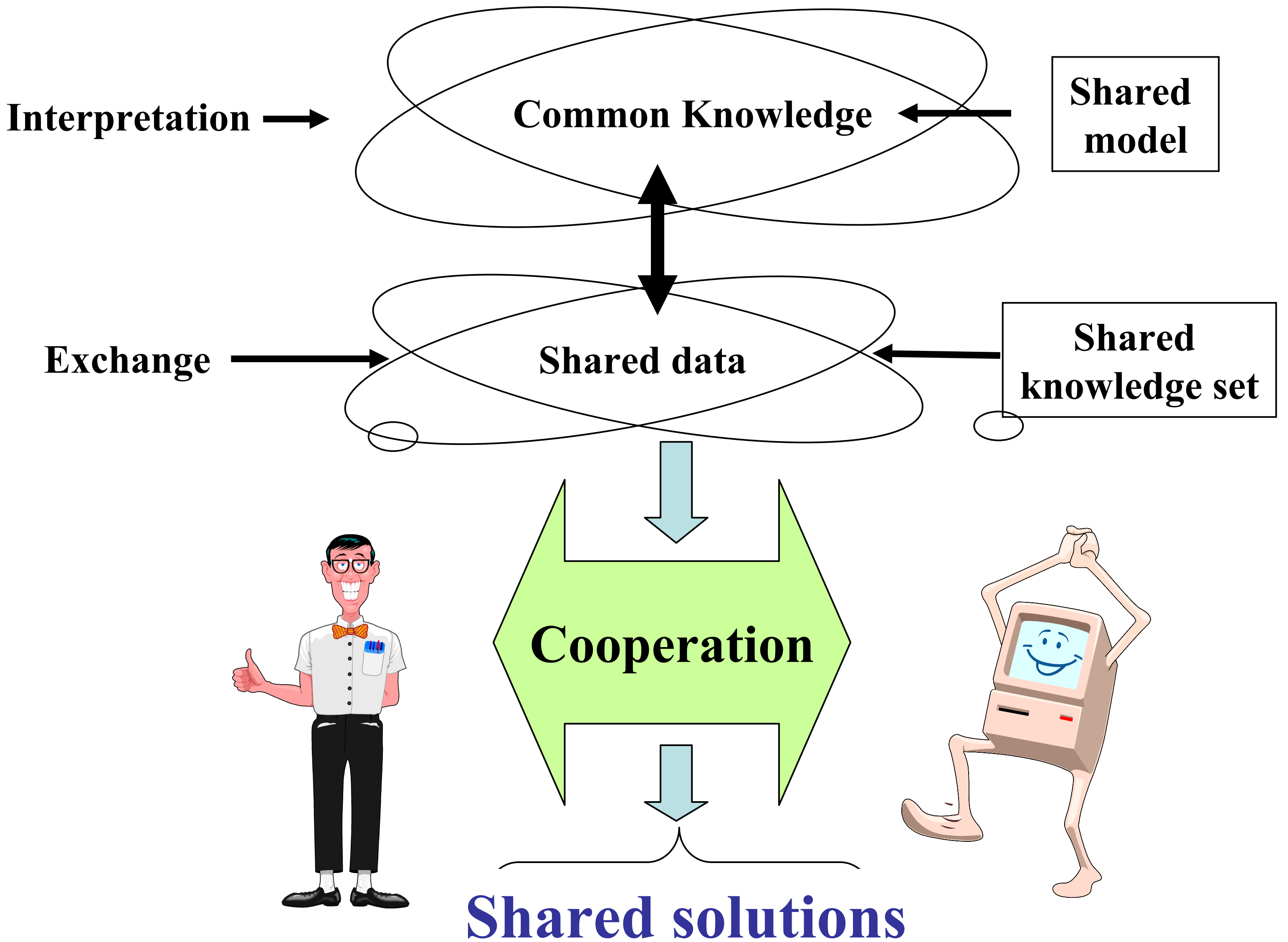
Example of integrative Cooperation applied to the diagnosis of a telephone network

The diagnosis tasks

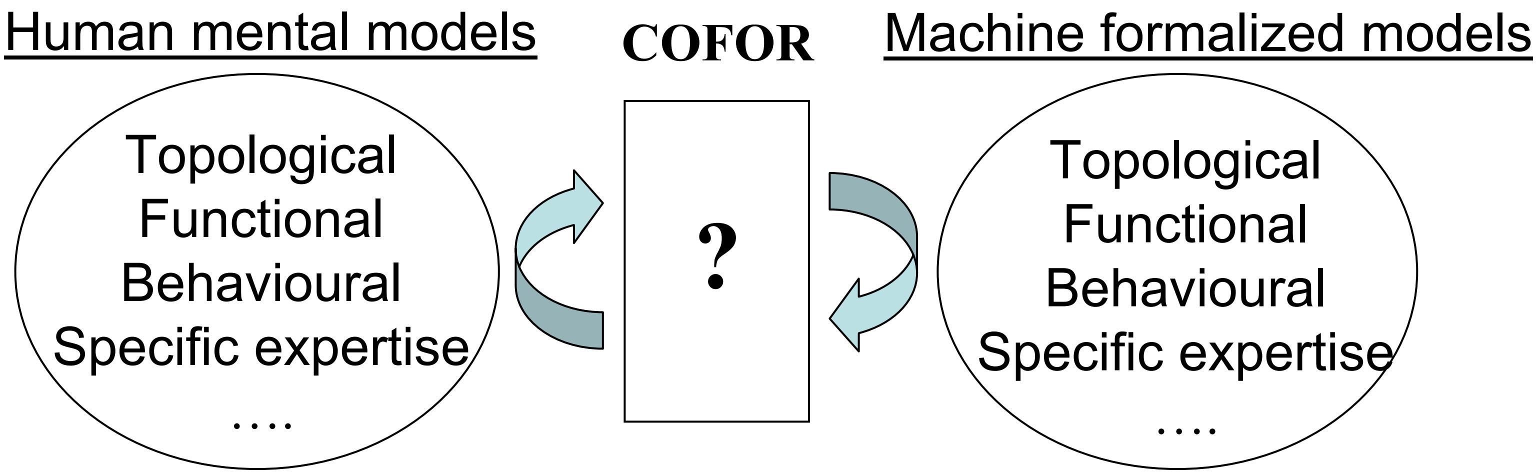


COFOR : COmmon Frame Of Reference [Hoc 1997]



What kind of knowledge in the COFOR ?

Different view-points are used by both human and machine to diagnose



Questions :

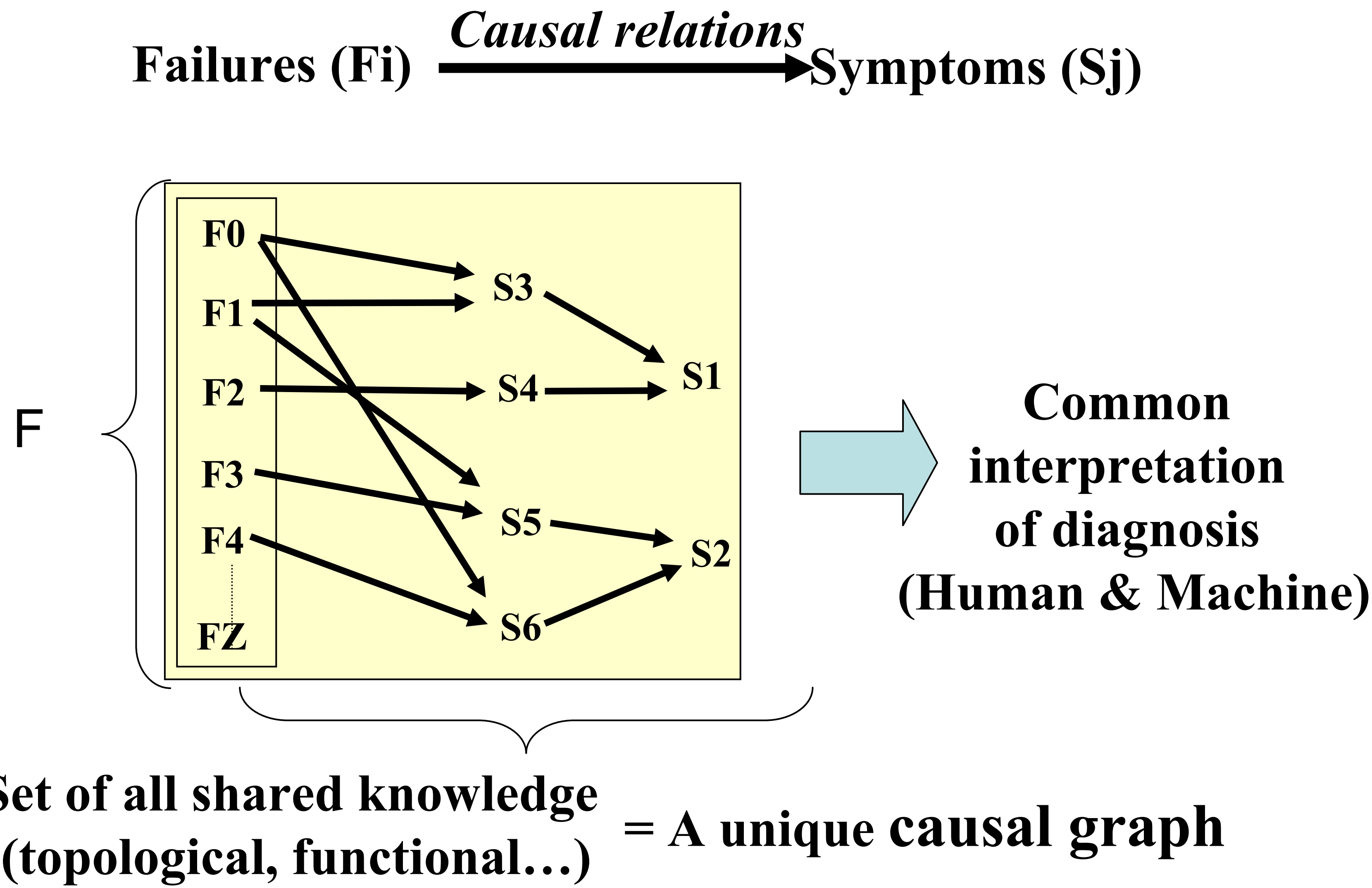
• Should knowledge shared in COFOR be uniform (human v.s. machine) ?

• Does the human-operator use particular kind of knowledge in some situations?

• What kind of knowledge should be integrated in COFOR for making cooperation easier?

•……?

A causal graph as a unique format for all view-points

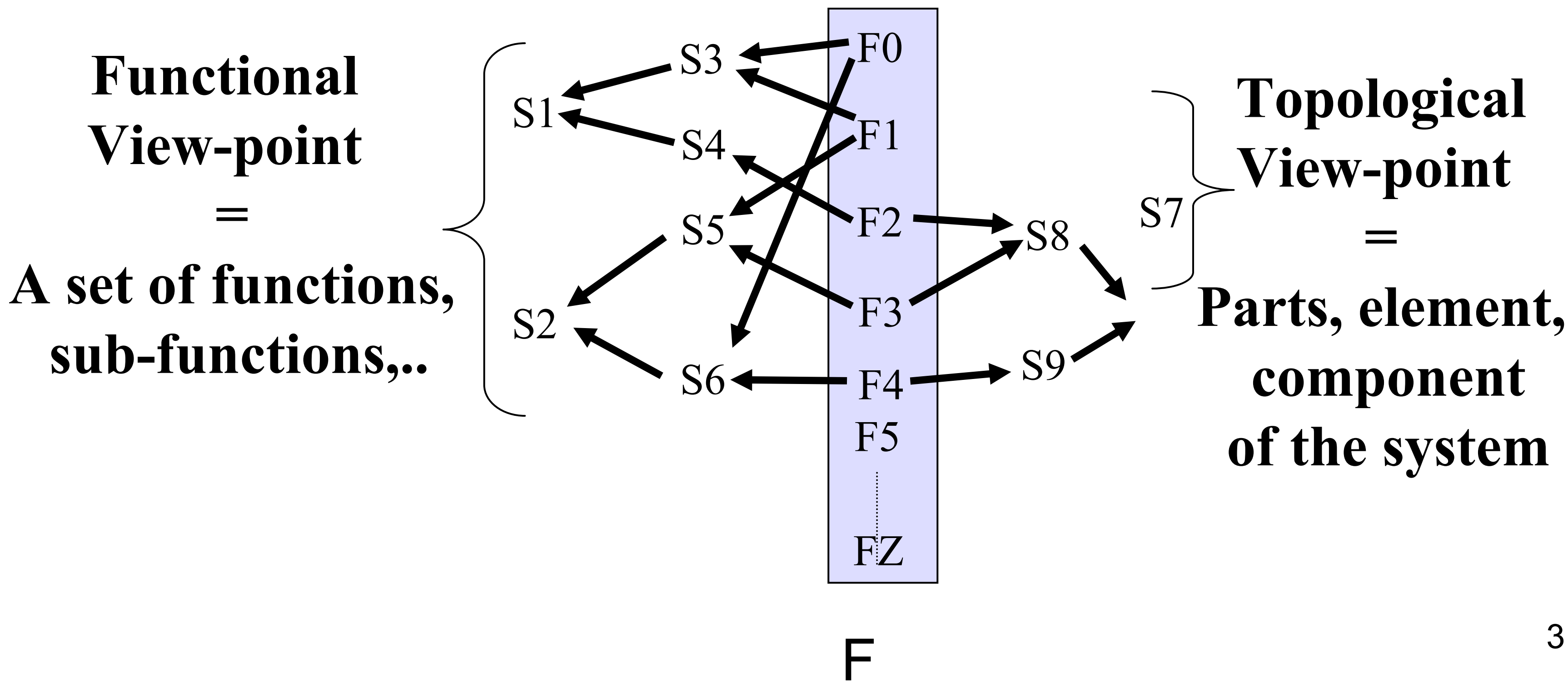


= A unique causal graph

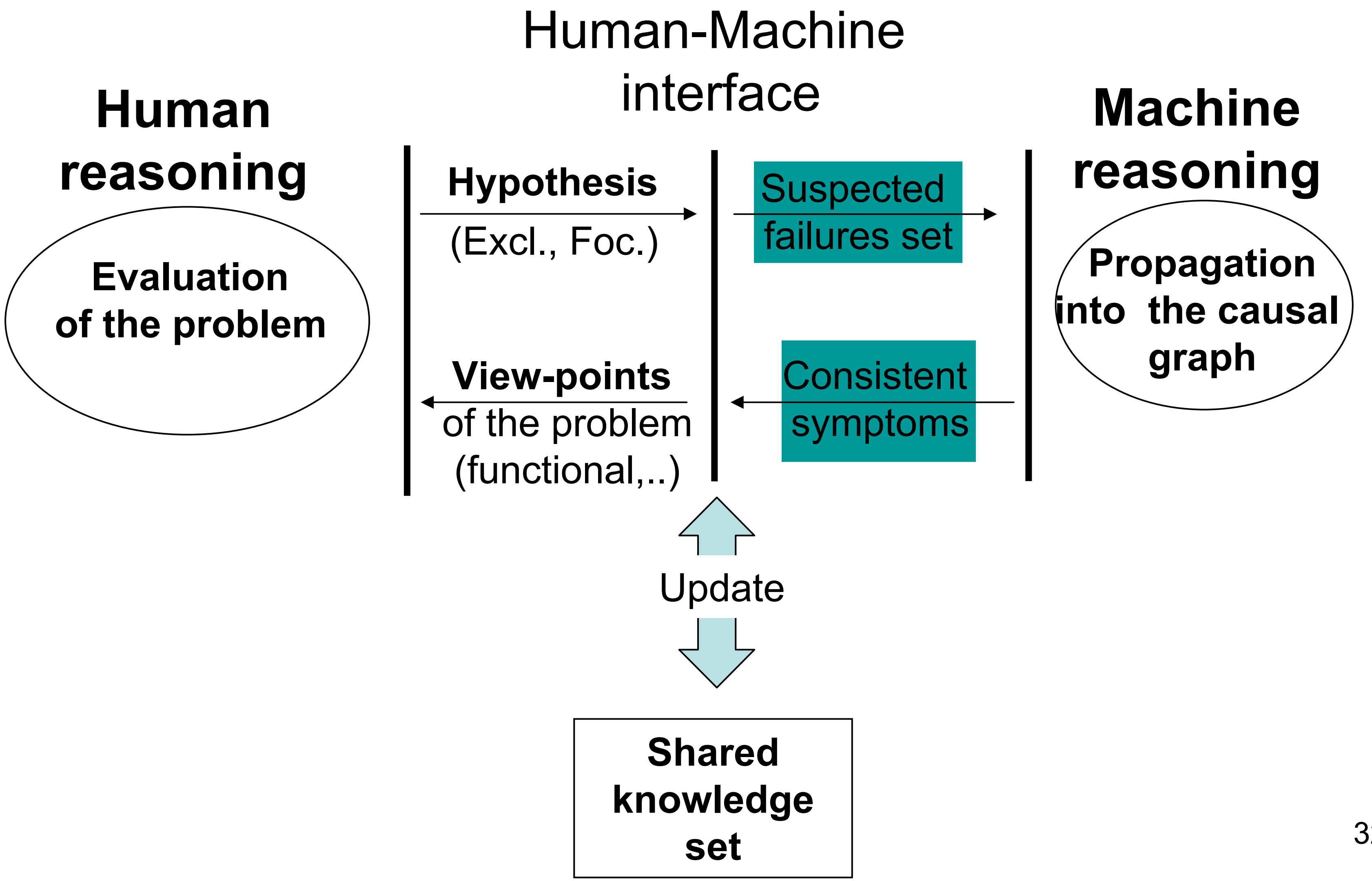
Different view-points through the causal graph

A causal graph for different view-points

- The view-points of the system are linked to a unique set of failures (F)
- Each view-point (e.g. functional) is a hierarchy of symptoms



Cooperative reasoning

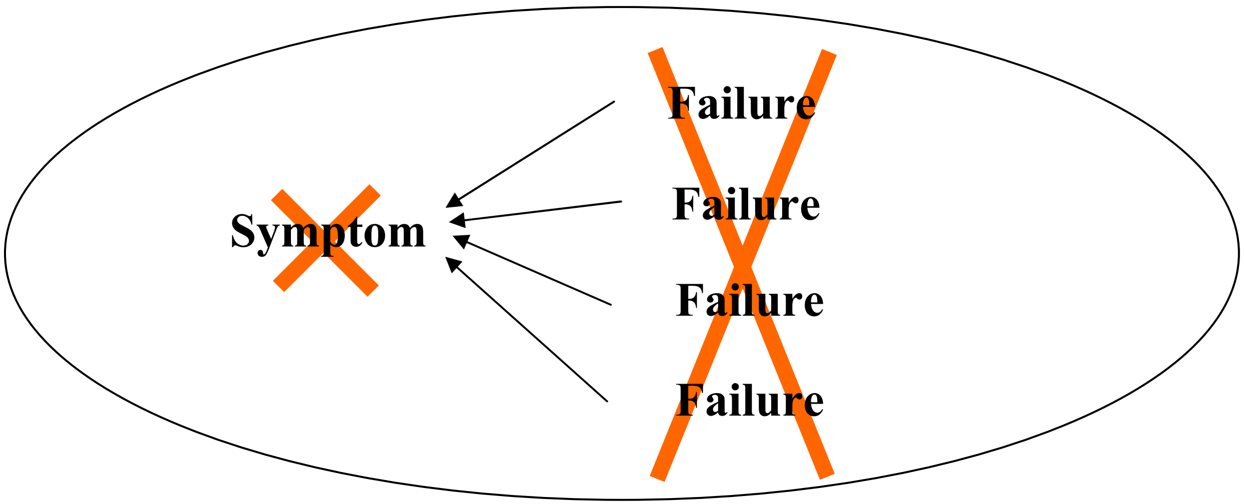


Reasoning on graph with causal implication

Using implication on causal relation :

$$\text{Failure} \rightarrow \text{Symptom} \equiv \neg\,\text{Symptom} \rightarrow \neg\,\text{Failure}$$

Part of the causal graph



An excluding operator Excl() is defined to consider symptoms which do not affect the process and to determine unsuspected failures:

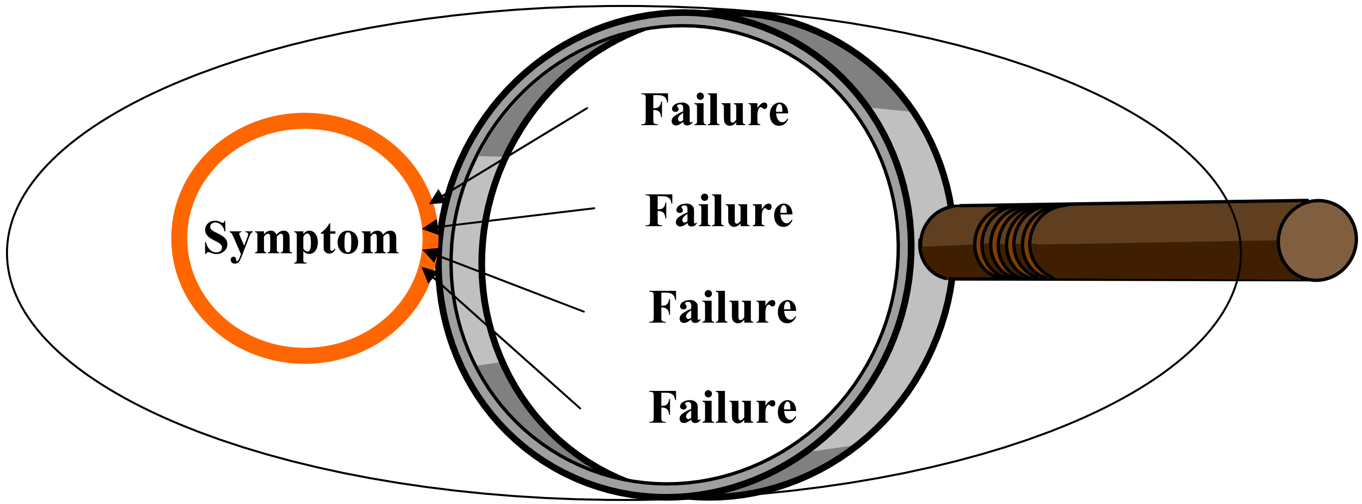
$$\forall S(H_p, K) \in \Phi\ H_p, F),\ E_{i+1} = Excl(S(H_p,K), E_i) = E_i - Failure(S(H_p,K))$$

Reasoning on graph with causal abduction

Using abduction on causal relation :

Failure $\rightarrow$ Symptom , Symptom $\vdash_{Abd.}$ Failure **[Poole 1992]**

Part of the causal graph



A focus operator Foc() is defined to consider symptoms affecting the process and to determine suspected failures:

$$\forall S(H_p, K) \in \Phi(H_p, F),\ E_{i+1} = Foc(S(H_p,K), E_i) = E_i \cap Failures(S(H_p,K))$$

Global application of the defined operators

- **Generation of suspect failures sets**

Hypothesis Generated by human → (**Excluding Excl()** / **Focusing Foc()**) →

{F1, F2, F4, F5}
{F4, F5}
…
{F1, F4, F5, F7}

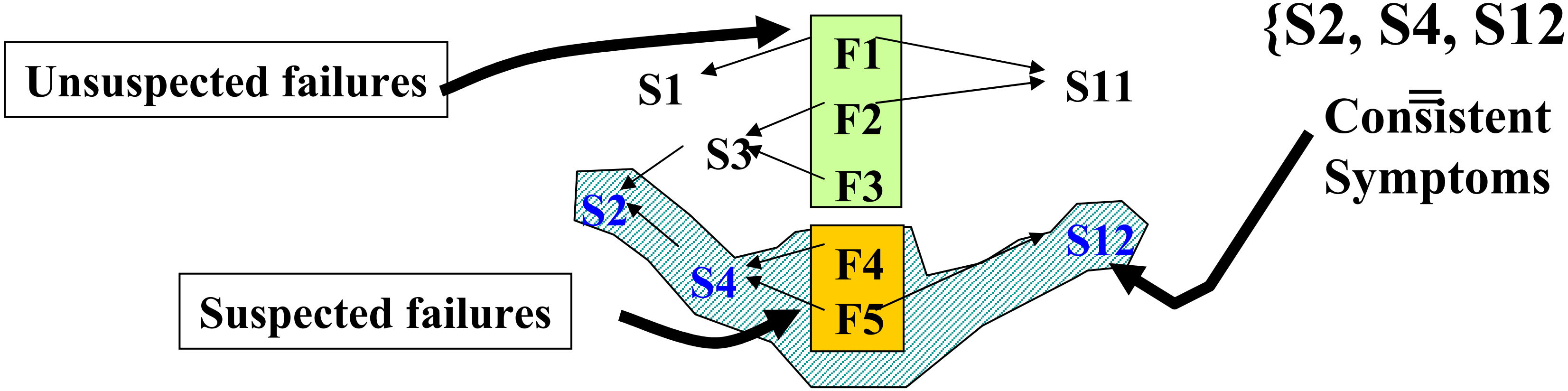
Several Suspected failure sets generated

- **Maintain the global reasoning consistency**

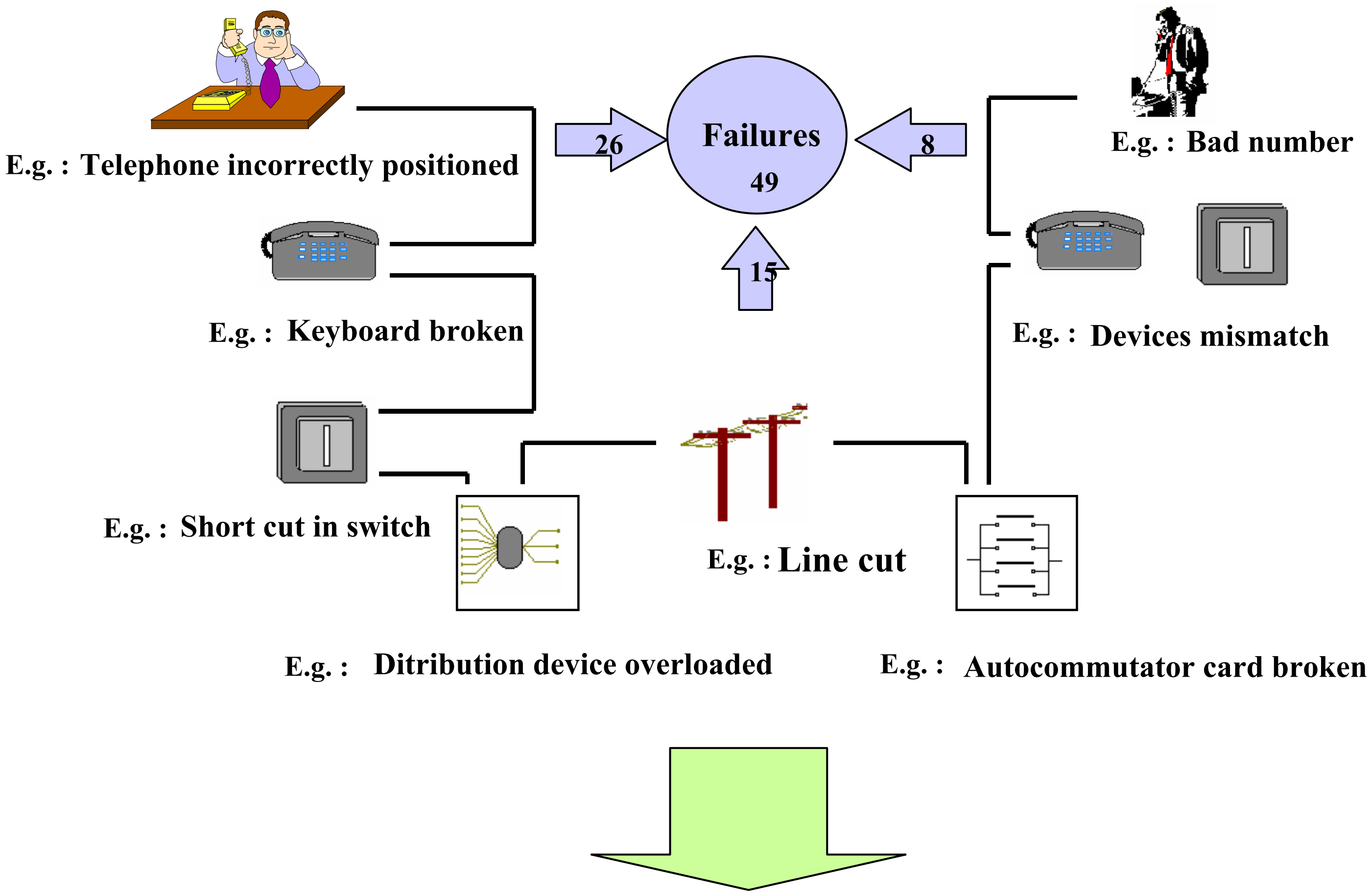
$\bigcap$ = {F4,F5} → **Updating the shared knowledge set**

- **Propagation into the causal graph in order to make symptoms consistent with suspected failures (symptoms that should appear)**

{S2, S4, S12}



Application to a telephone network diagnosis



49 Failures

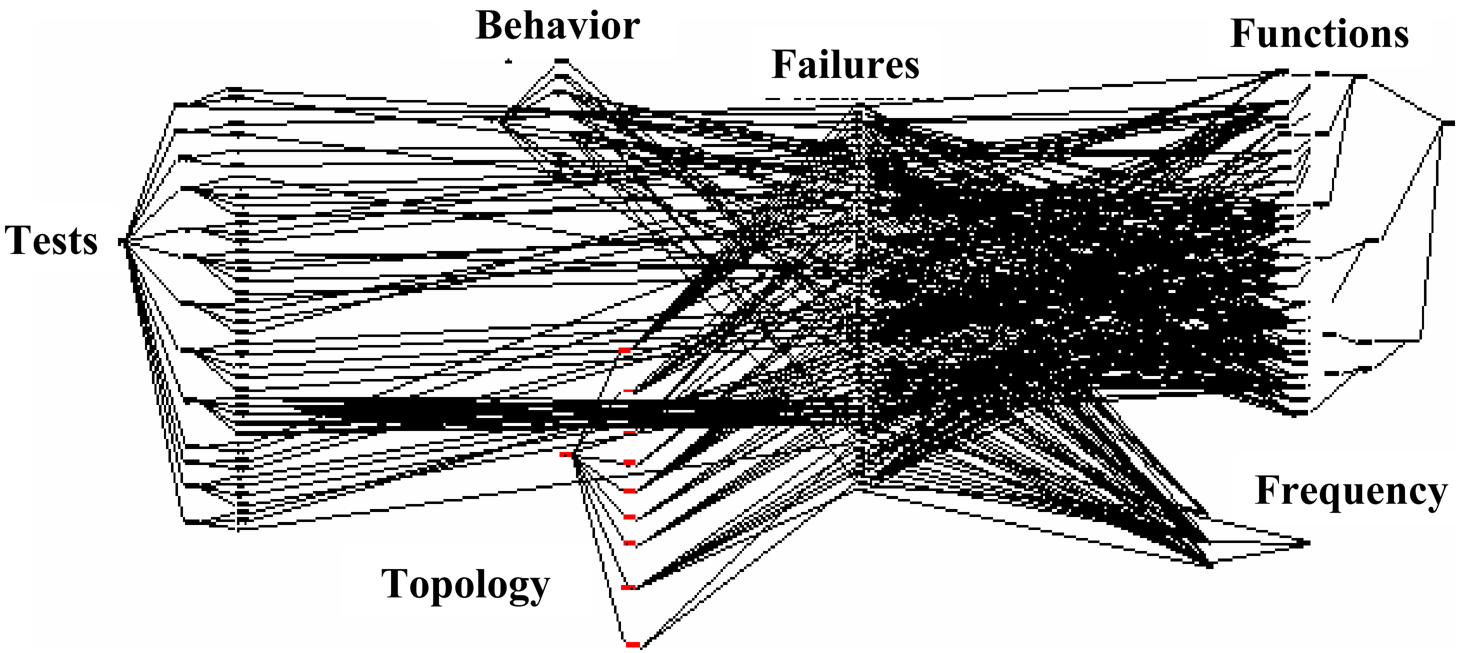
Five view-points of the system

5 view-points

- Topological ⇨ Elements, parts, components
- Functional ⇨ Function, sub-functions available (or not)
- Behavioural ⇨ Typical malfunctionning symptoms
- Tests ⇨ Test available
- Frequency ⇨ Frequency of the failure occurrence

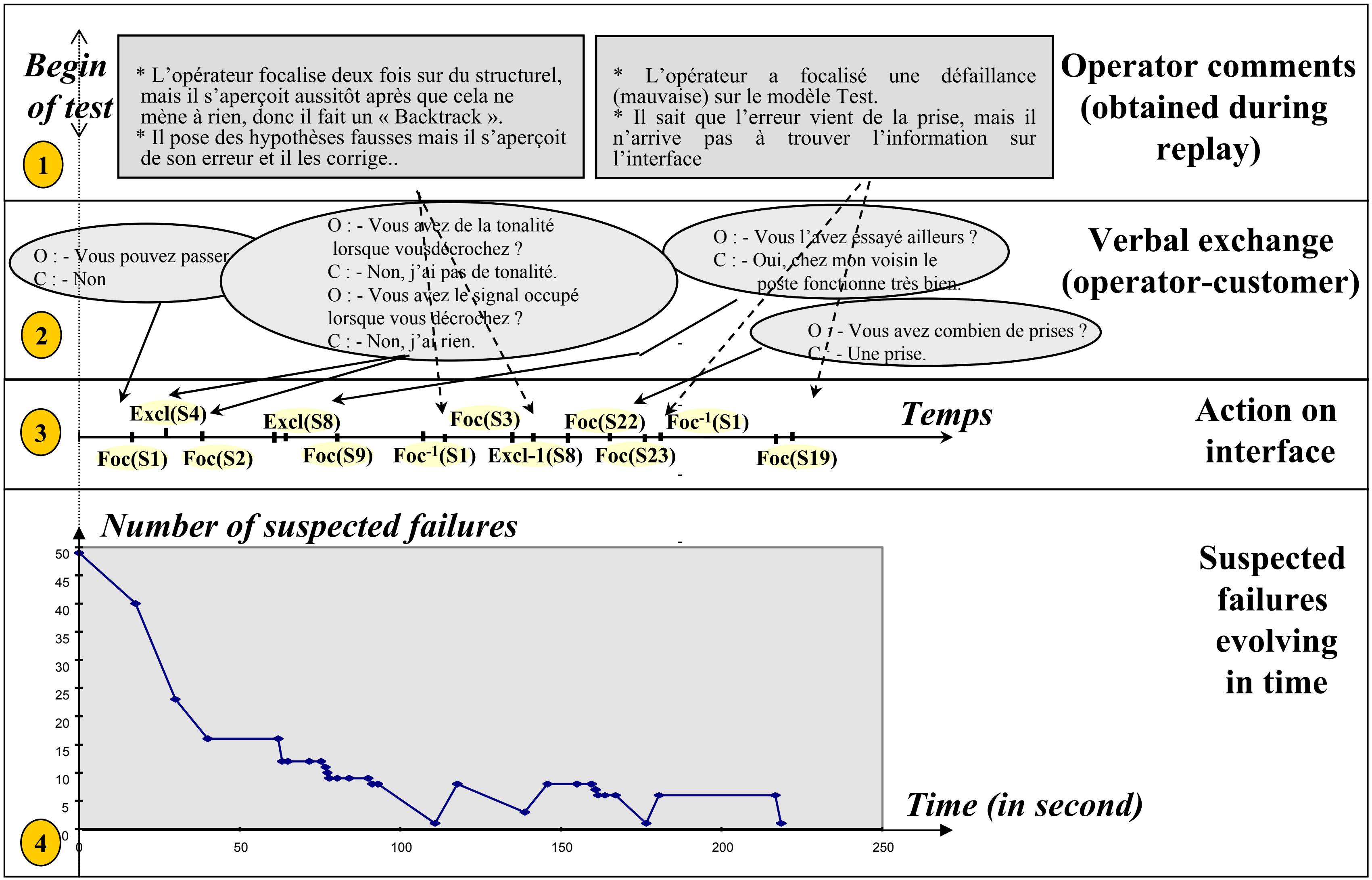
⬇

- **500 causal links**
- **120 terminal nodes**

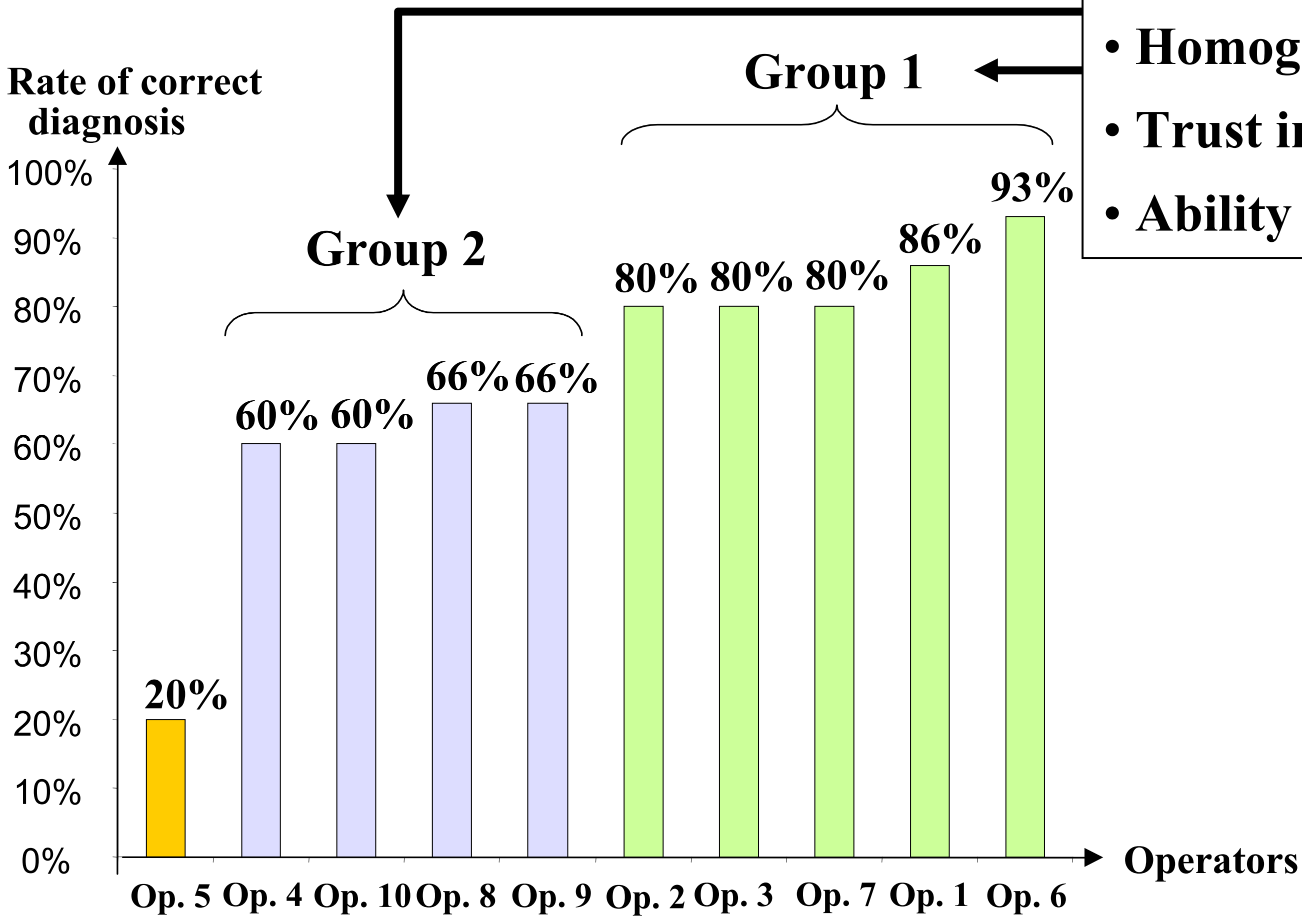


Causal graph

Synthesis of collected data



Human-machine team performance



- Homogeneous performance
- Trust in machine support
- Ability to use interface

Success of diagnosis with or without correcting

Correct diagnosis = 75,4%		Wrong diagnosis = 24,6%	
Without correction	With a correction	With a correction	Without correction
57,5%	17,9%	18,6%	6%

36,5%

Success of the integrative cooperation

Limits :

- Errors were detected

Problem :

- Errors not detected

Several errors still remain undetected or difficult to be corrected by operator

Cooperation was usefull

Partial results : 3 operators X 15 cases (constraint in real situation)

	Human-machine cooperation	**Human alone**
Correct Diagnosis	**82%**	**64%**
Time	2 min. 11 sec	2 min.

Efficiency increased

Temporal cost very low

View-point using rate

Frequency	Topological	Functional	Behavioral	Tests
0,7%	15,5%	38%	20,6%	25,2%

- Misunderstood
- Not very usefull for human operators

- 4 view-points were useful and used
- Complementarity of view-point
- Flexibility of switching between view-point during reasoning
- Similar to human mental models

Operators ' comments

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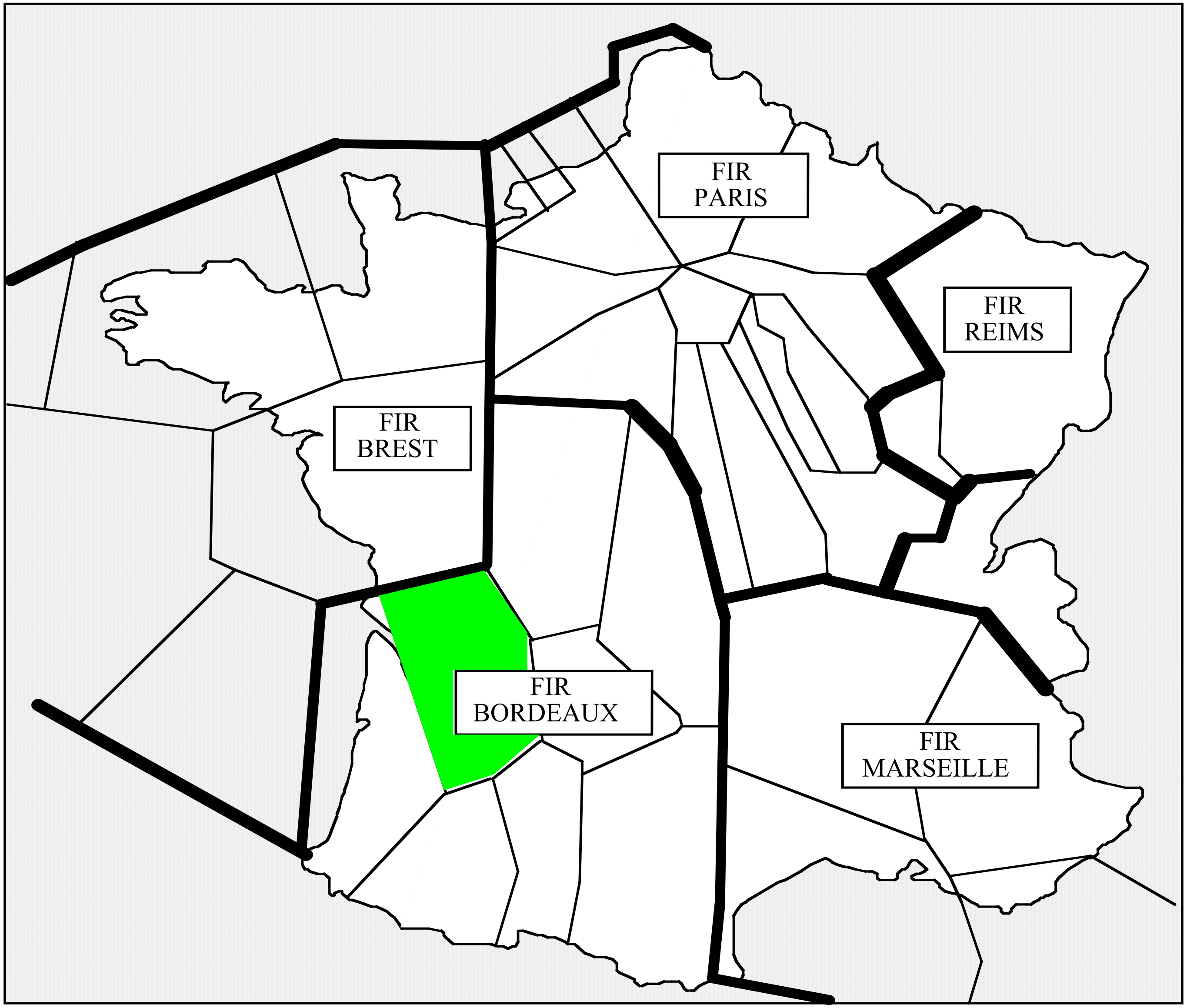
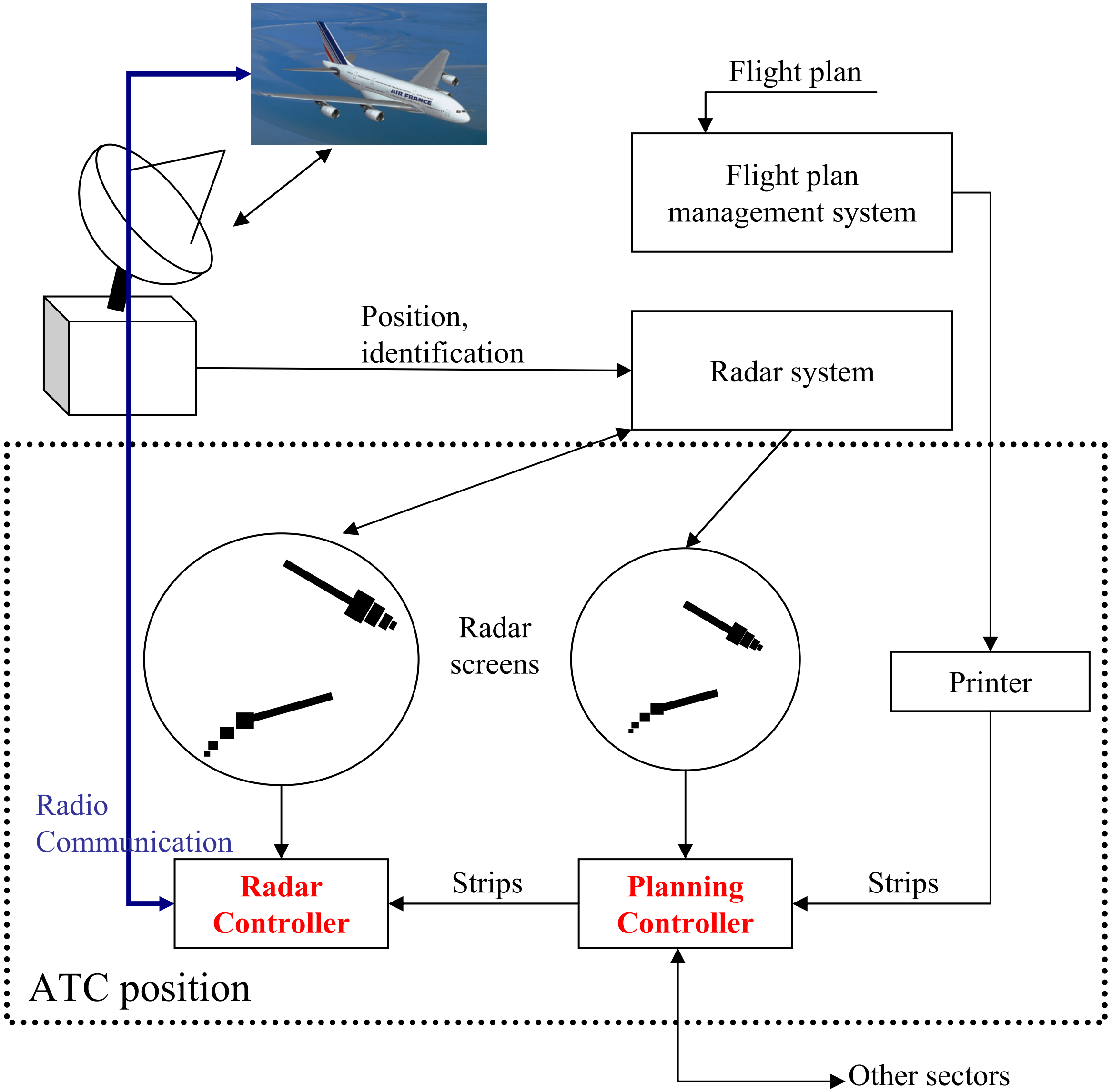
Example of Cooperation in the Air Traffic Control

Organisation of the French Air-Traffic Control

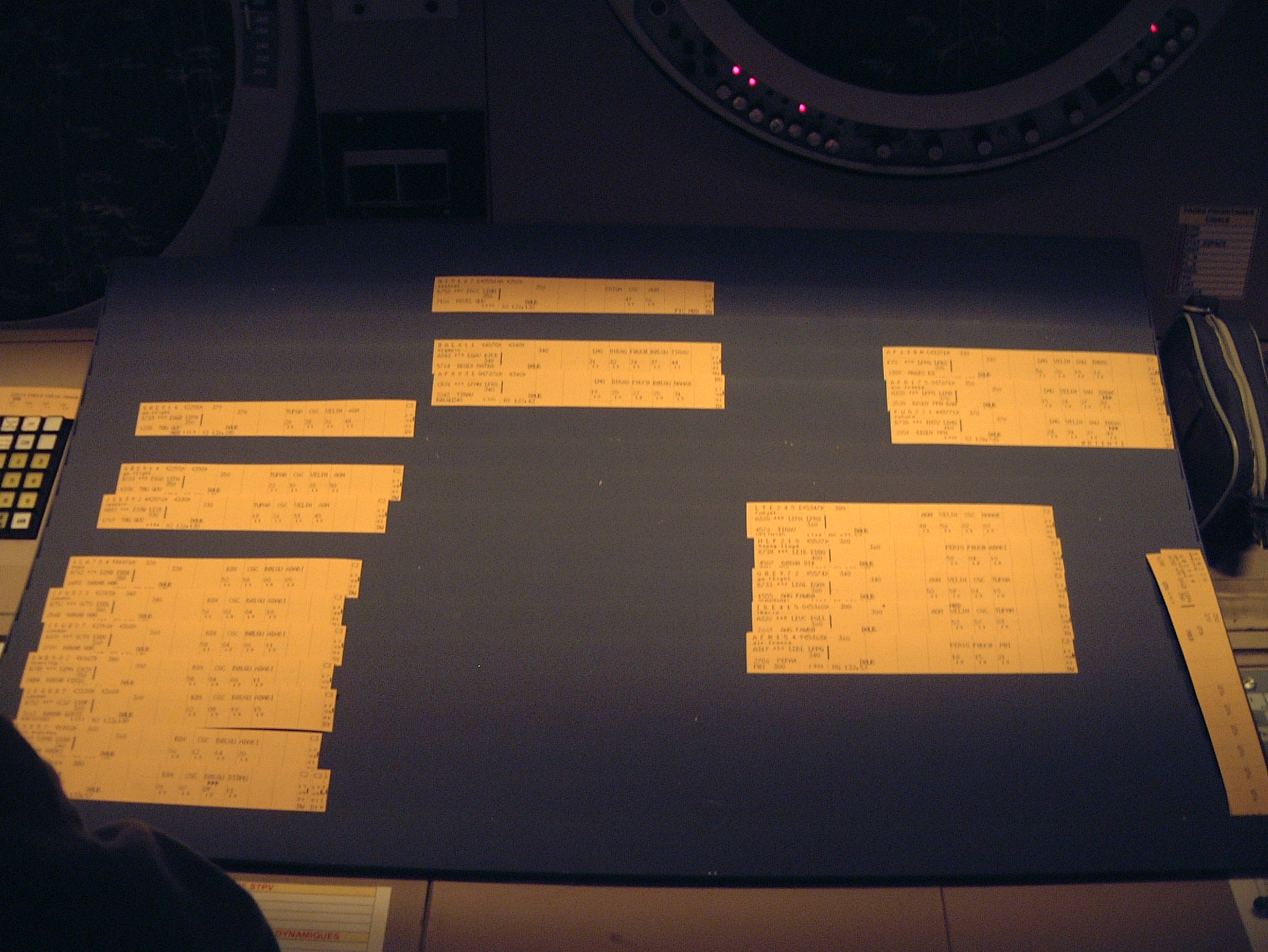


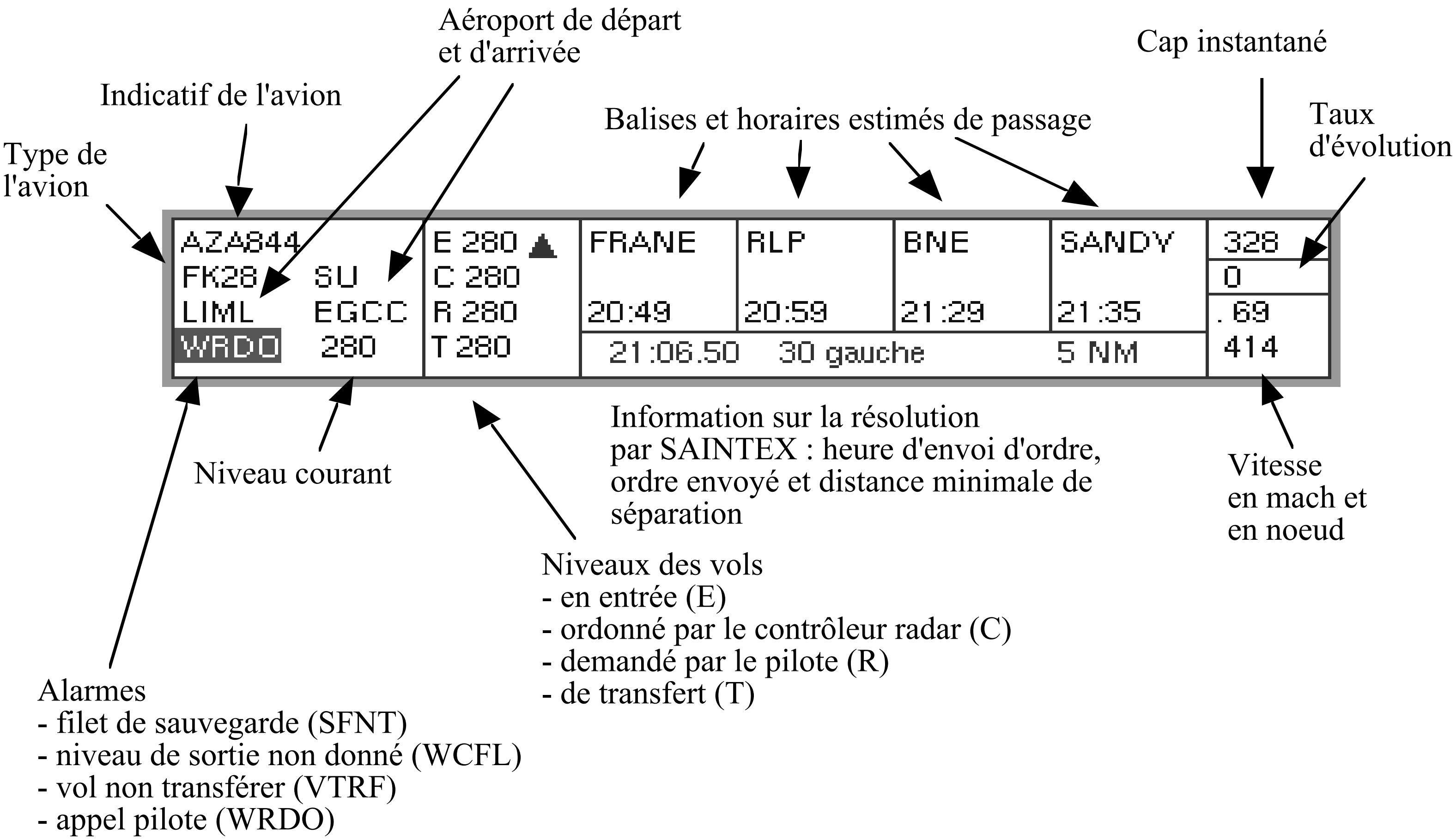
Organisation of the French Air-Traffic Control




PSD V2
SIMUL


SIMUL
PSE H1
H1 H2 N1 Z1
FL
275


STPV
DYNAMIQUES


Aéroport de départ
et d'arrivée
Cap instantané
Indicatif de l'avion
Balises et horaires estimés de passage
Taux
d'évolution
Type de
l'avion
AZA844
FK28 SU
LIML EGCC
WRDO 280
E 280
C 280
R 280
T 280
FRANE
RLP
BNE
SANDY
20:49
20:59
21:29
21:35
21:06.50 30 gauche 5 NM
328
0
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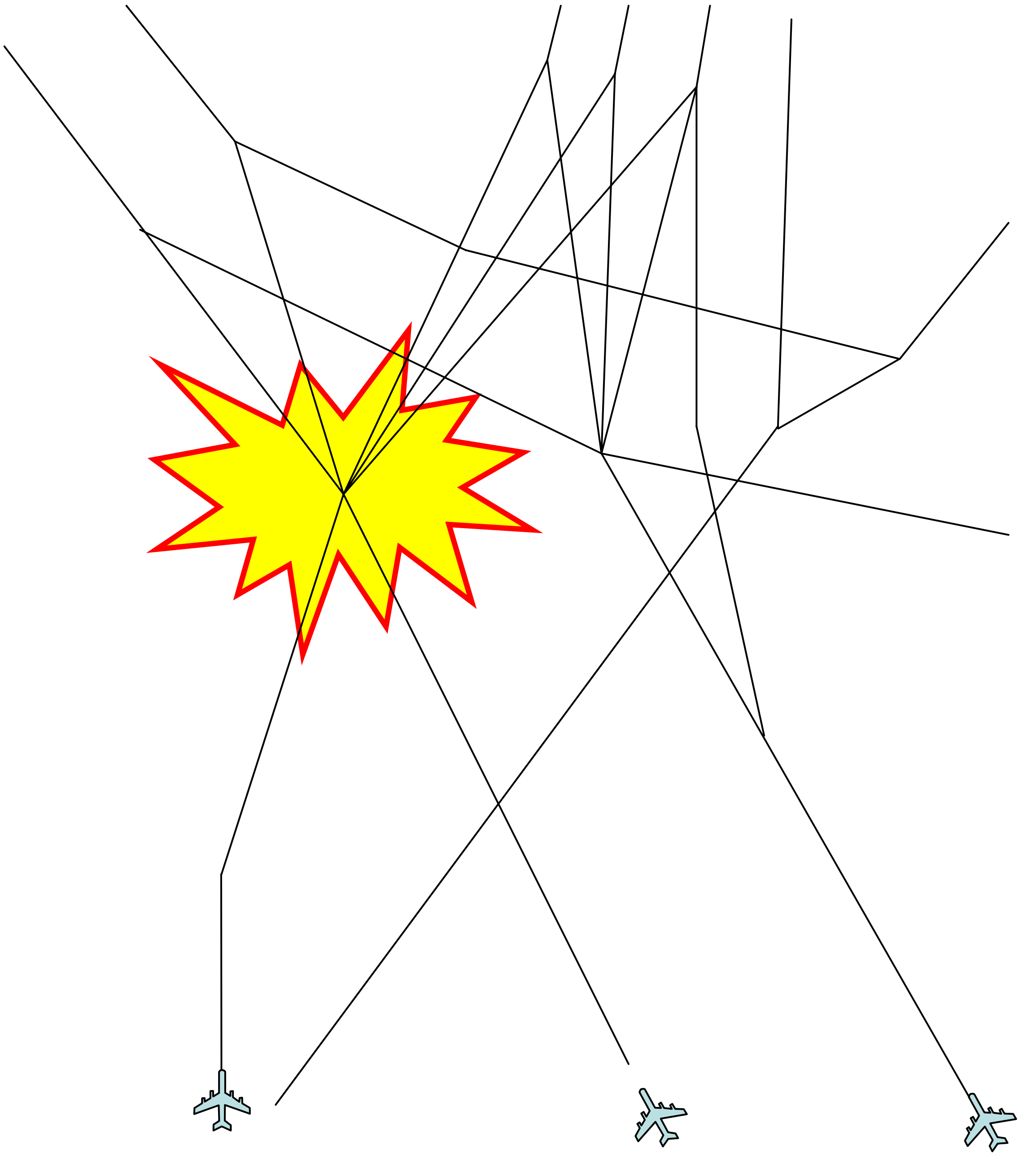
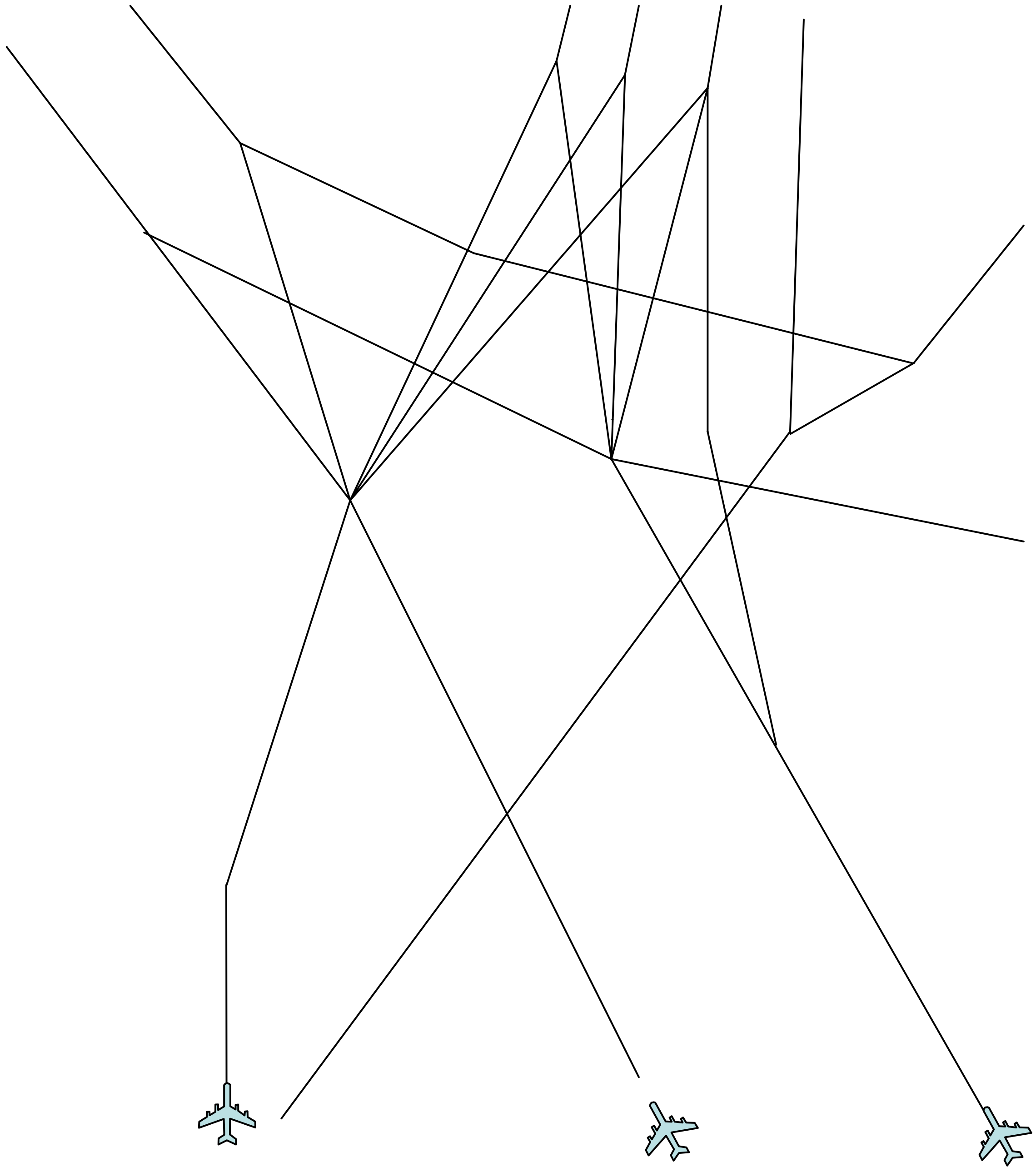
414
Information sur la résolution
par SAINTEX : heure d'envoi d'ordre,
ordre envoyé et distance minimale de
séparation
Niveau courant
Vitesse
en mach et
en noeud
Niveaux des vols
- en entrée (E)
- ordonné par le contrôleur radar (C)
- demandé par le pilote (R)
- de transfert (T)
Alarmes
- filet de sauvegarde (SFNT)
- niveau de sortie non donné (WCFL)
- vol non transférer (VTRF)
- appel pilote (WRDO)

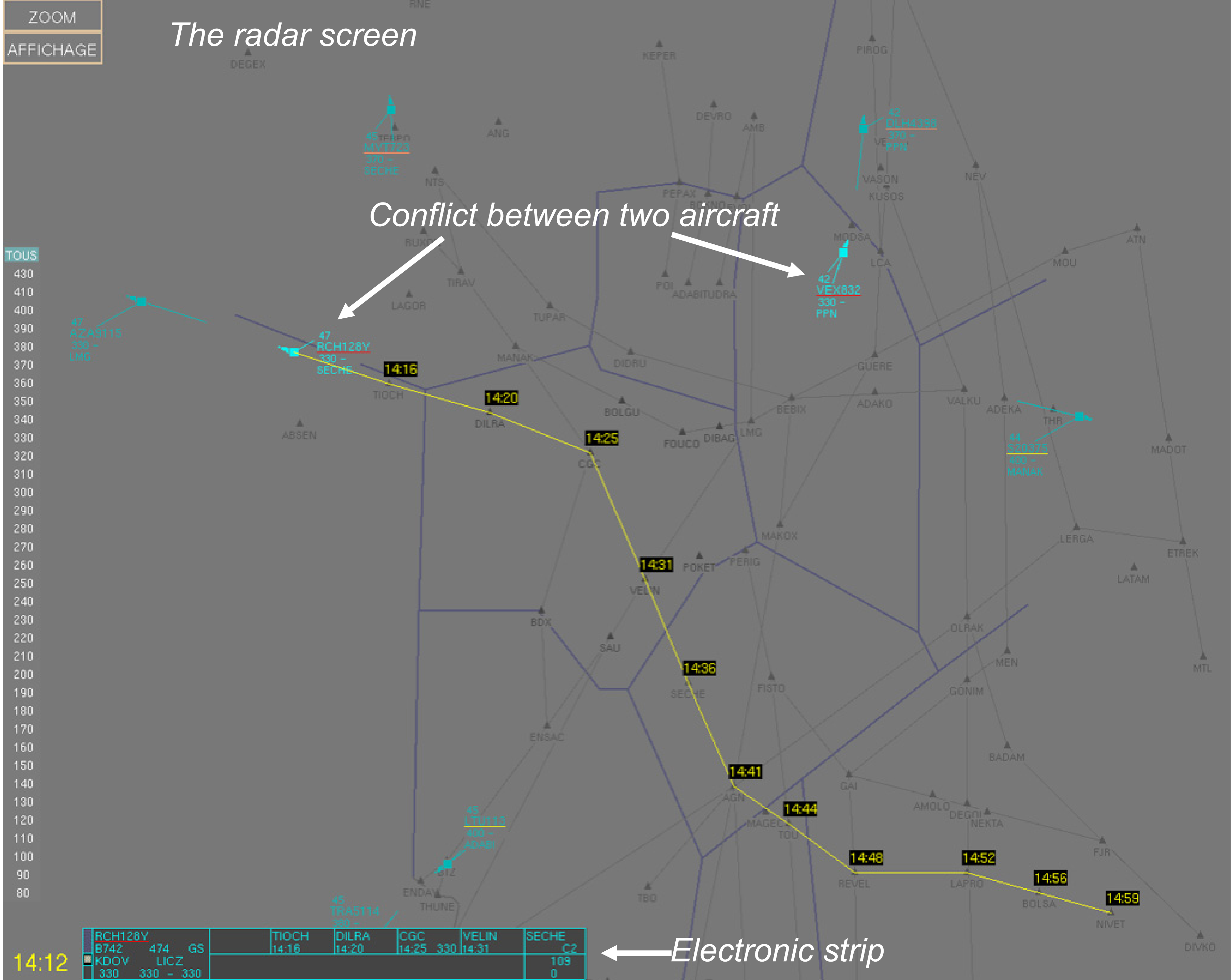




ATC position

- 2,5 millions aircraft over French air space in 2002
- Estimated increase: 3 - 5 % per year
- How to assume this increase with the same safety high level ?:

=> an assistance tool


The radar screen
Conflict between two aircraft
Electronic strip
ZOOM
AFFICHAGE
TOUS
RCH128Y
330 -
SECHE
14:16
14:20
14:25
14:31
14:36
14:41
14:44
14:48
14:52
14:56
14:59
RCH128Y
B742 474 GS
KDOV LICZ
330 330 - 330
TIOCH 14:16
DILRA 14:20
CGC 14:25 330
VELIN 14:31
SECHE C2
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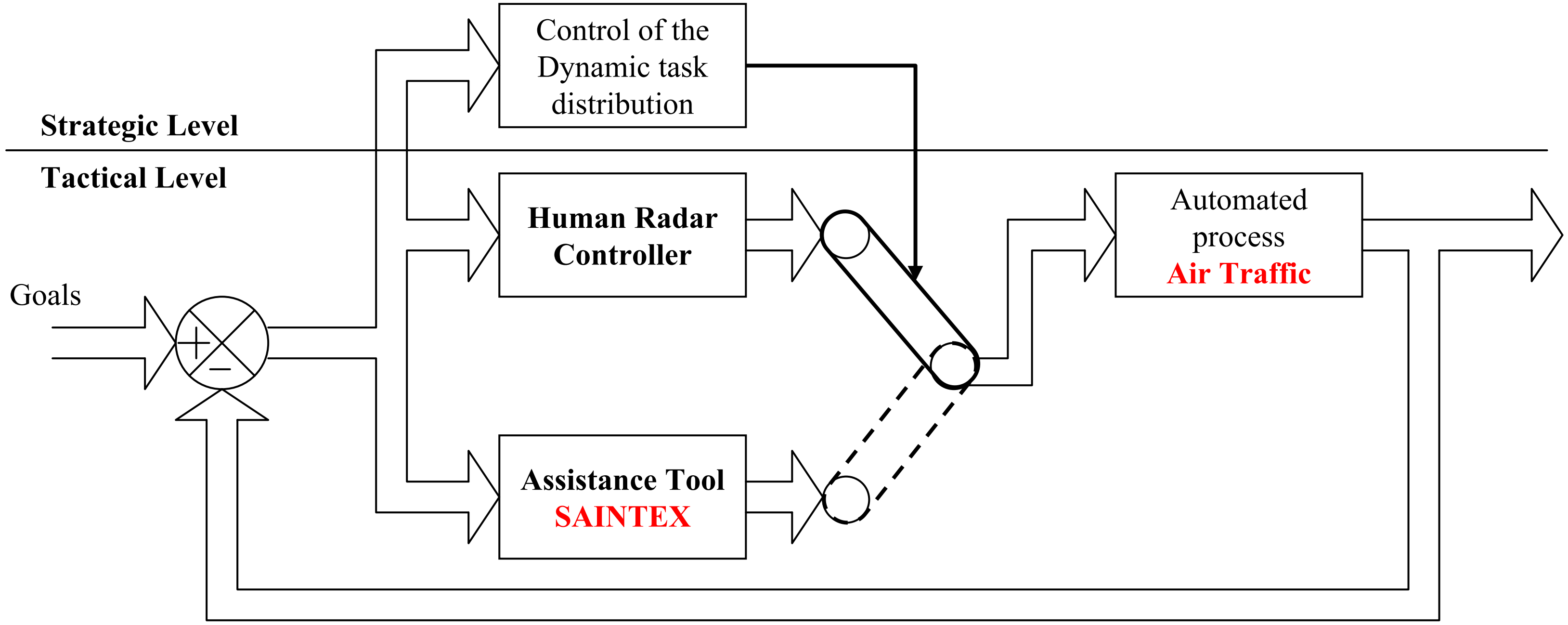
14:12

Human-Machine Cooperation: augmentative form



SPECTRA V1 & SPECTRA V2 Projects:

- Dynamic task distribution
- Autonomous Assistance Tool (problem detection, strategy, solution, command)

Hypotheses to test experimentally:

- Human Workload decreases ?
- Global Traffic performance increases ?

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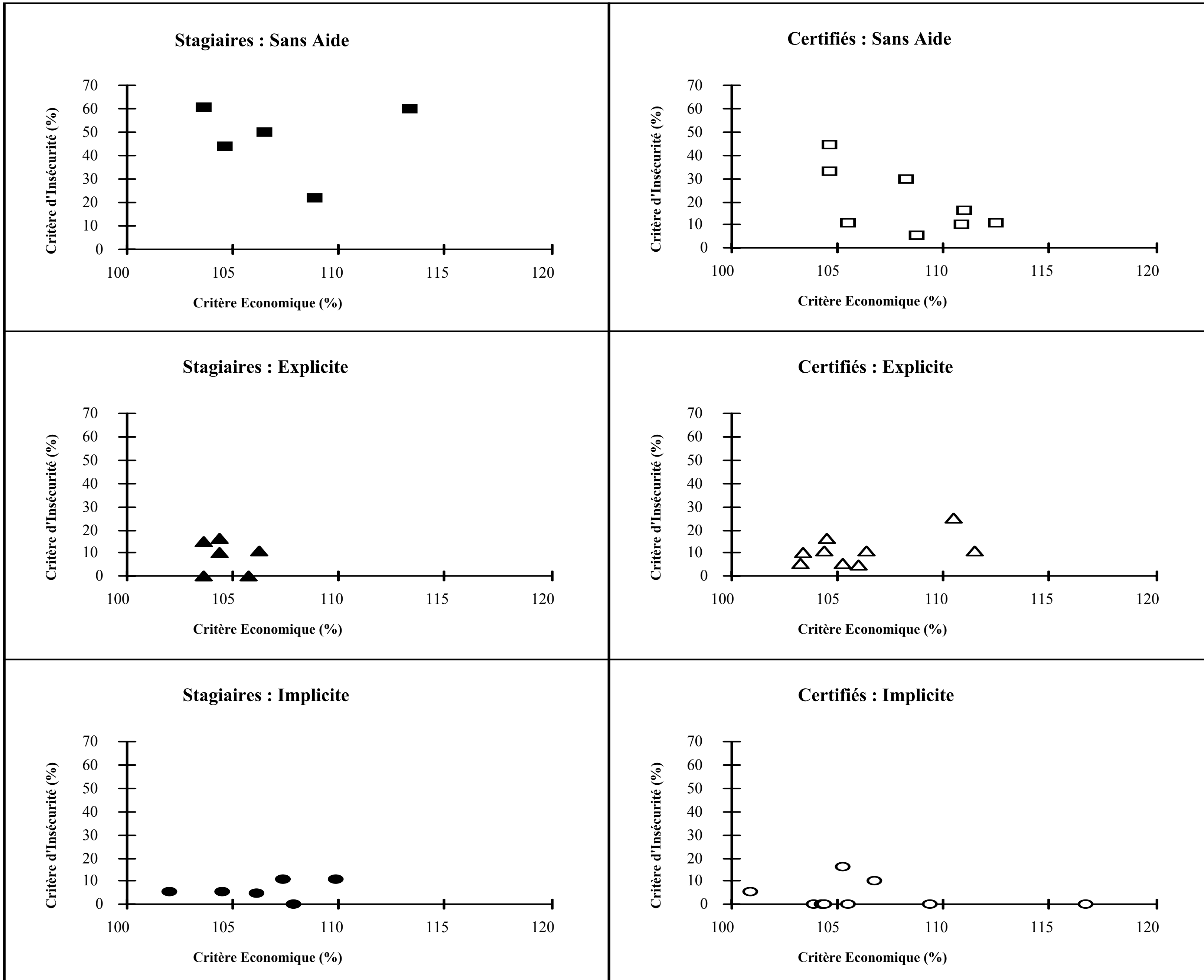
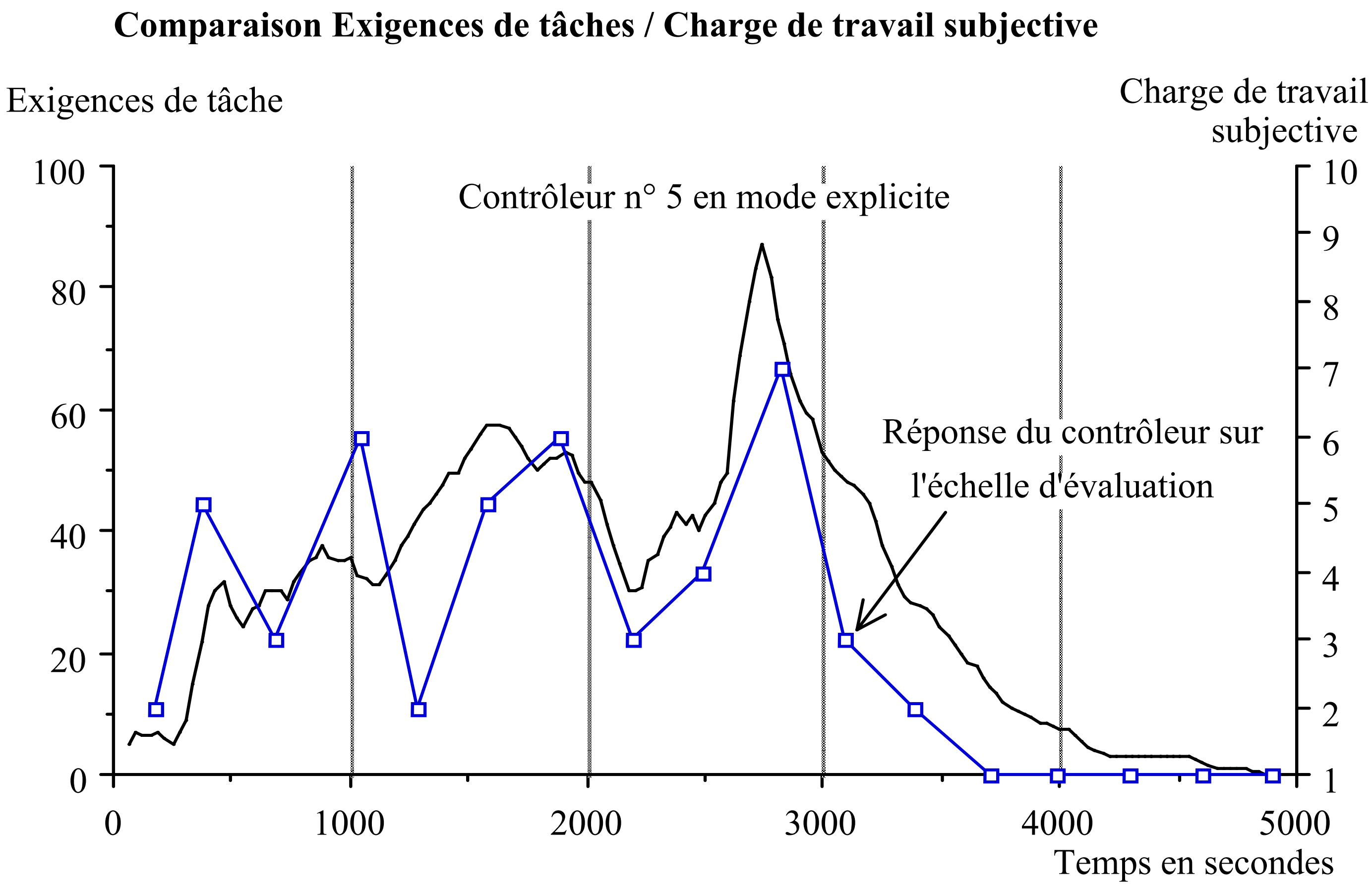
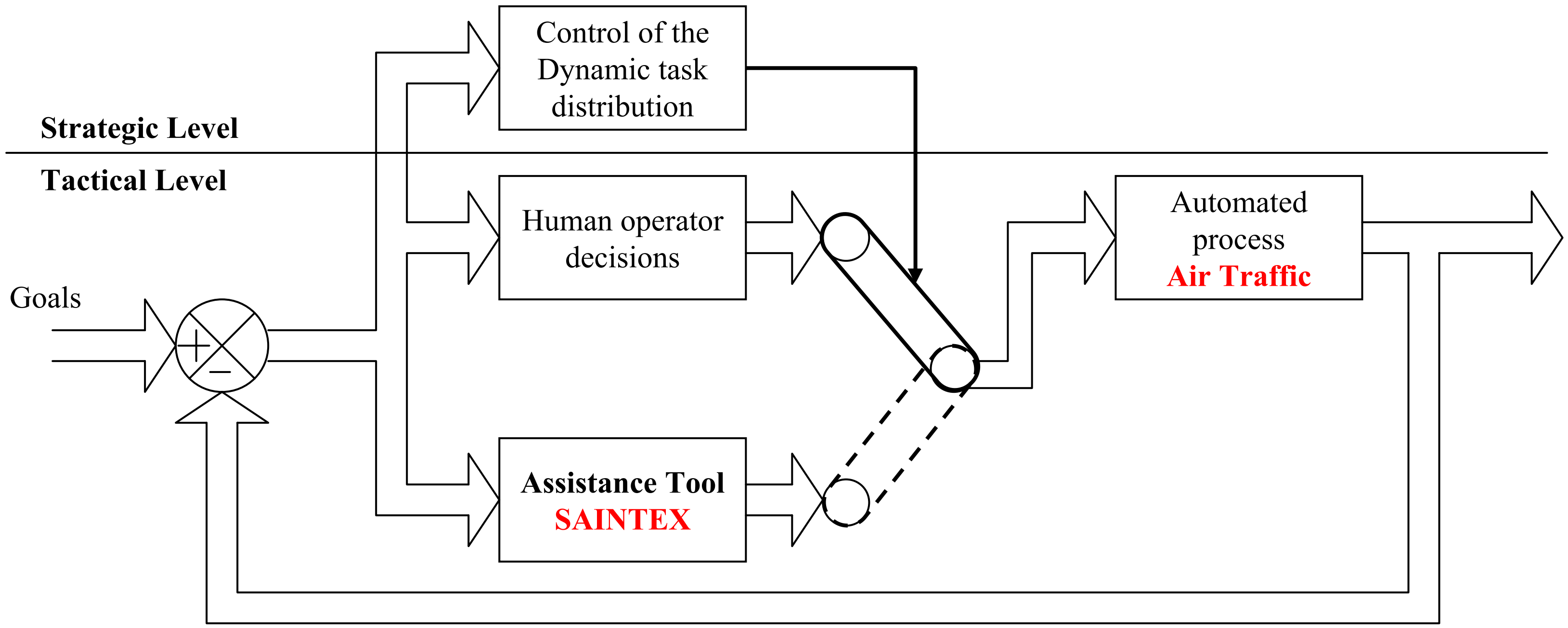


Global performance according to both controller expertise levels and the 3 control modes: without any assistance, explicit mode and implicit mode



Example of comparison between tasks demands and subjective WL along time for the controller no 5 in an experiment with SAINTEX in explicit mode

Human-Machine Cooperation: augmentative form



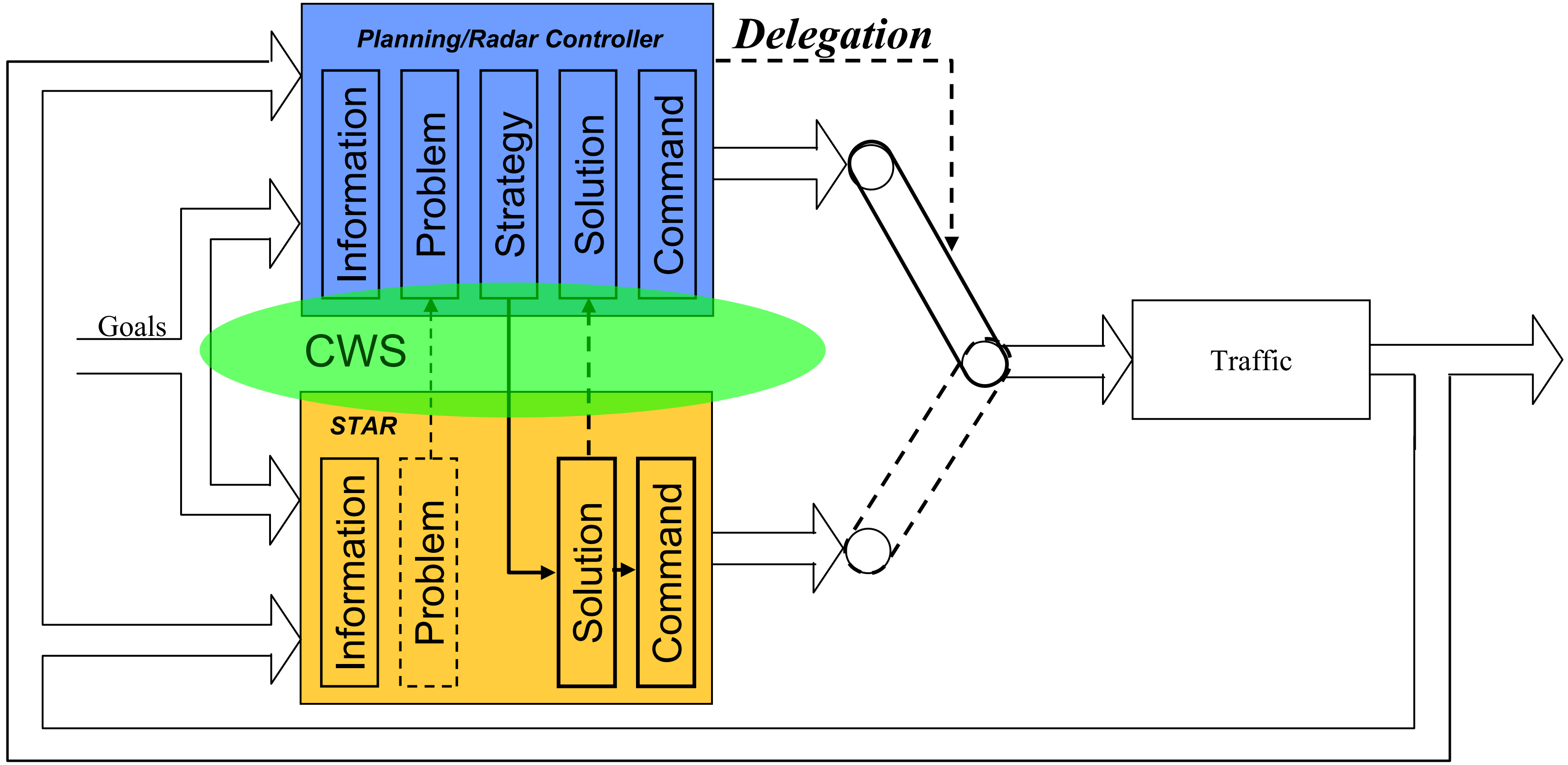
SPECTRA V1 & SPECTRA V2 Projects: Results

- Dynamic task distribution
- Autonomous Assistance Tool SAINTEX (problem detection, strategy, solution, command)
- The hypotheses are verified: Human Workload decreases and global performances increase

But :

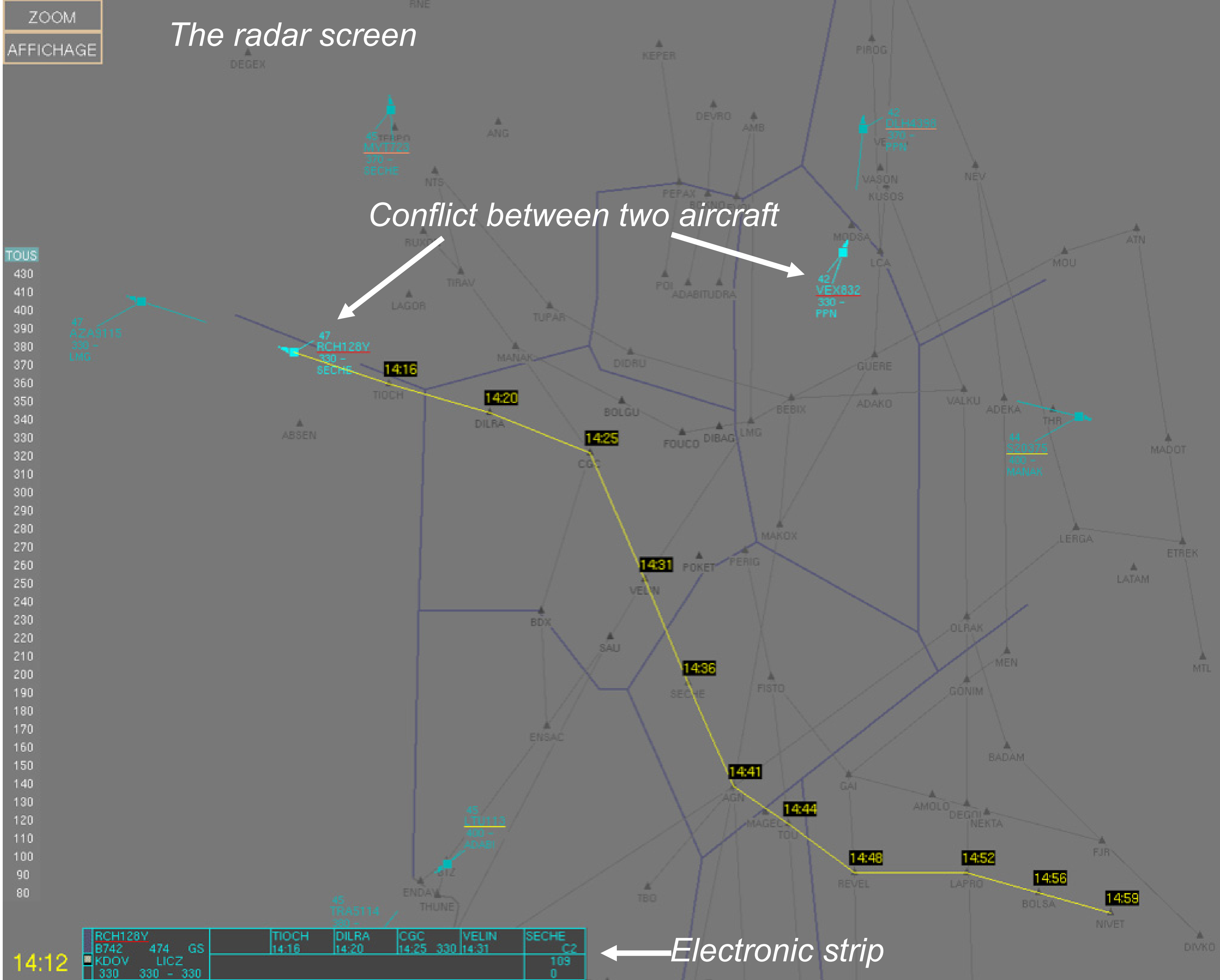
- Negative interferences between controllers and SAINTEX:
  - Problems in the definition and the allocation of the tasks
  - Divergence in the resolution strategies between the Human and SAINTEX
  - Organisational and juridical difficulties

Human-Machine Cooperation: multiple forms

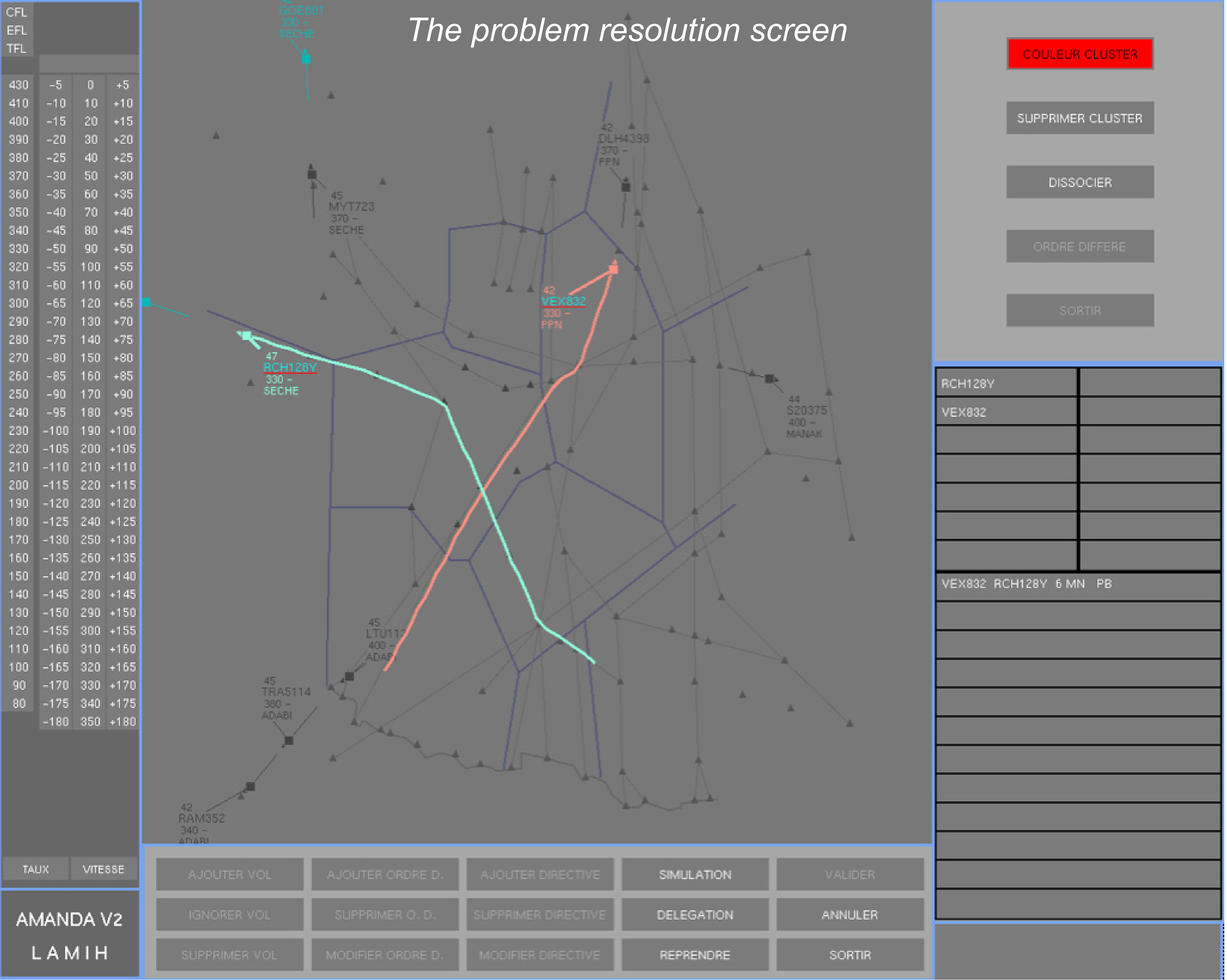


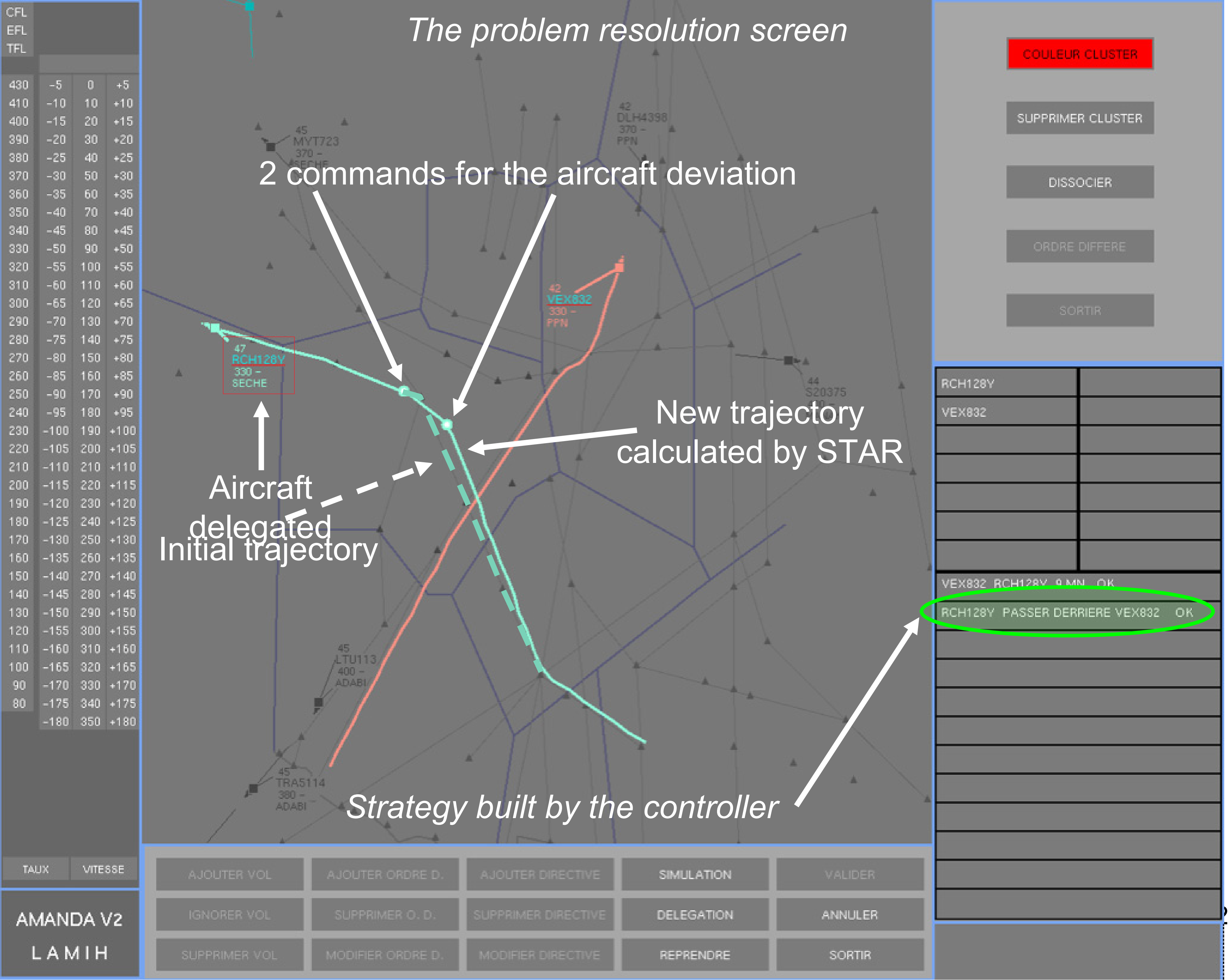
AMANDA Project:

- Definition of a new **support tool called STAR** that integrates human strategies for calculating and implementing solutions
- Definition of a **Common Work Space CWS** that allows both agents (human and artificial) to share information and to negotiate

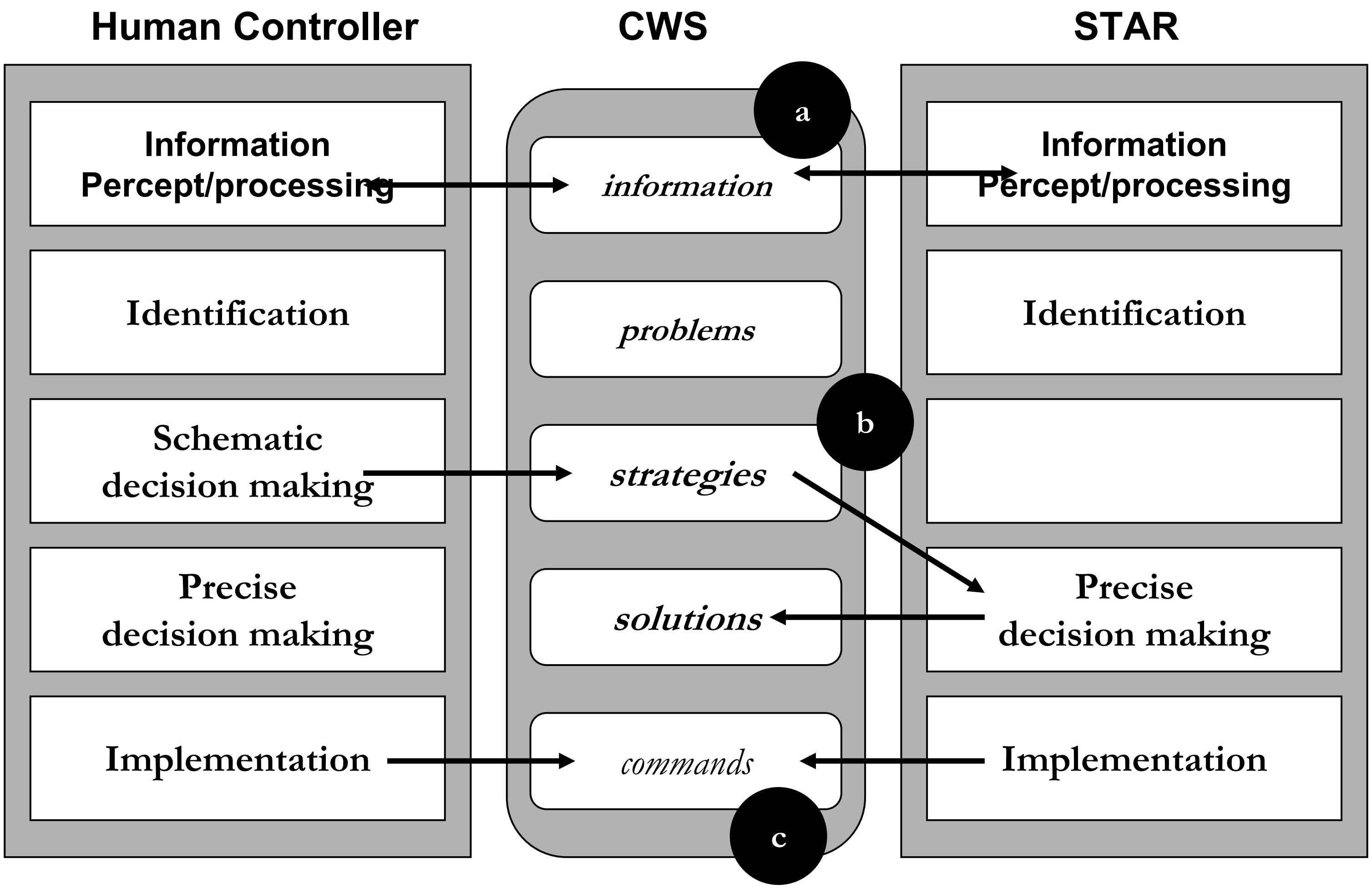

The radar screen
Conflict between two aircraft
Electronic strip
ZOOM
AFFICHAGE
TOUS
14:12
RCH128Y
B742 474 GS
KDOV LICZ
330 330 - 330
TIOCH 14:16
DILRA 14:20
CGC 14:25 330
VELIN 14:31
SECHE C2
109
0

The problem resolution screen




The problem resolution screen
2 commands for the aircraft deviation
New trajectory calculated by STAR
Aircraft delegated
Initial trajectory
Strategy built by the controller
COULEUR CLUSTER
SUPPRIMER CLUSTER
DISSOCIER
ORDRE DIFFERE
SORTIR
RCH128Y
VEX832
RCH128Y PASSER DERRIERE VEX832 OK
AJOUTER VOL
AJOUTER ORDRE D.
AJOUTER DIRECTIVE
SIMULATION
VALIDER
IGNORER VOL
SUPPRIMER O. D.
SUPPRIMER DIRECTIVE
DELEGATION
ANNULER
SUPPRIMER VOL
MODIFIER ORDRE D.
MODIFIER DIRECTIVE
REPRENDRE
SORTIR
TAUX
VITESSE
AMANDA V2
LAMIH

Human-Machine Cooperation: multiple forms



a: debative

b: integrative

c: augmentative

Conclusion

1. The results of these experiments:

- show an increase of performance when Human cooperates with the machine

- stress the need to allow error recovery means to achieve performance

- stress the importance of the COFOR

2. Further studies are needed:

-for modelling and implementing cooperation in action with applications for instance to car driving tasks

- for discovering the task parameters which contribute or refrain cooperation: workload, trust and self confidence, motivation

Thank you for your attention

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