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arianeGroup

A FIRST CYBER-PHYSICAL SYSTEMS OF SYSTEMS MODELING

Olivier MAURICE

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01

TAN PRINCIPLES

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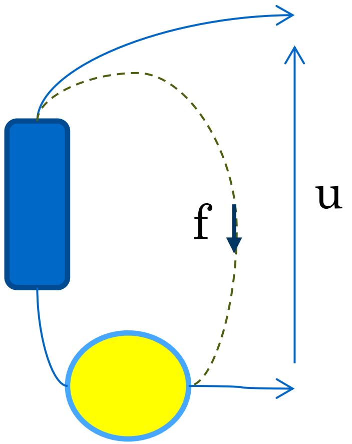
any object can be characterized using an excitation e (mechanical, electrical, …, one).
This creates a flux f (current, movement, …).
If we open the circuit a potential energy appears U.

e, U are scalars → covectors
f is a vector component
z(p, …) is an operator (leads to a metric)

$$e_\nu = z_{\nu\alpha} . f^{\alpha} + u_\nu \ *$$



*Kirchhoff's fundamental law

TAN PRINCIPLES

Fundamental mesh space and problem lagrangian

$$\begin{cases} e_\nu = z_{\nu\alpha}.f^\alpha + u_\nu \\ f^\alpha = \Lambda^\alpha_\beta k^\beta \end{cases} \Rightarrow e_\nu = z_{\nu\alpha}.\Lambda^\alpha_\beta k^\beta + u_\nu$$

$$\Lambda^\nu_\gamma e_\nu = \Lambda^\nu_\gamma z_{\nu\alpha}.\Lambda^\alpha_\beta k^\beta + \Lambda^\nu_\gamma u_\nu$$

but $\Lambda^\nu_\gamma u_\nu = 0$

with $\Lambda^\nu_\gamma e_\nu = \breve{e}_\gamma$ *and* $\Lambda^\nu_\gamma z_{\nu\alpha}.\Lambda^\alpha_\beta = \breve{z}_{\gamma\beta} \Rightarrow$ $\breve{e}_\gamma = \breve{z}_{\gamma\beta}.k^\beta$

02

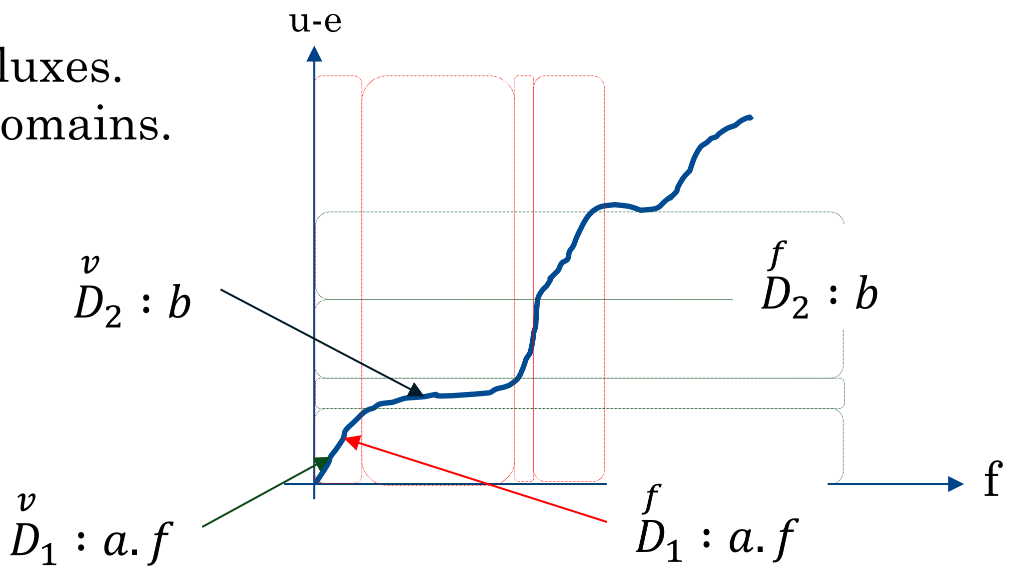
METRIC AND OPERATORS

METRIC AND OPERATORS

Fundamental principle tensor of TAN formalism: $\breve{z}_{\gamma\beta}$

it contains operators applied to fluxes.
These operators are defined on domains.

$$z = \overset{v}{D}_1 \overset{f}{D}_1 a(.) + \overset{v}{D}_2 \overset{f}{D}_2\, b + \ \ldots$$



METRIC AND OPERATORS

$$\zeta_{ij} = \overset{p}{D}_1 L^1_{ij} + \overset{p}{D}_2 L^2_{ij} + \dots$$

Using these kind of operators, temperature and other environment parameters can be taken into account easily.

Non linear behaviors, i.e. real behaviors can be taken into account.

This technique gives the tool to model any hardware side of CPSoS:

- electronics
- lines and antennas
- power chopper, electrical machines, energy sources, ...
- sensors, active skin,
- ...

03

ON MACROMODELING

ON MACROMODELING

Complex systems are made of many parts. To conduct their analysis, it's impossible to consider the whole system or even some whole subsystem like the harnesses.

Two keys give the method to conduct this analysis:

- ❖ using macromodels;
- ❖ studying only couples and using diakoptics to make conclusion on the whole subsystem.

ON MACROMODELING

exemple

An object a interacts with an object b

$$z = \begin{bmatrix} a & 0 \\ \alpha & b \end{bmatrix} \Rightarrow k = -\frac{\alpha e}{ab}$$

An object a interacts with two object b and b with b

$$z = \begin{bmatrix} a & 0 & 0 \\ \alpha & b & \beta \\ \alpha & \beta & b \end{bmatrix} \Rightarrow k = -\frac{\alpha e}{a(b+\beta)}$$

n objects coupled by pairs

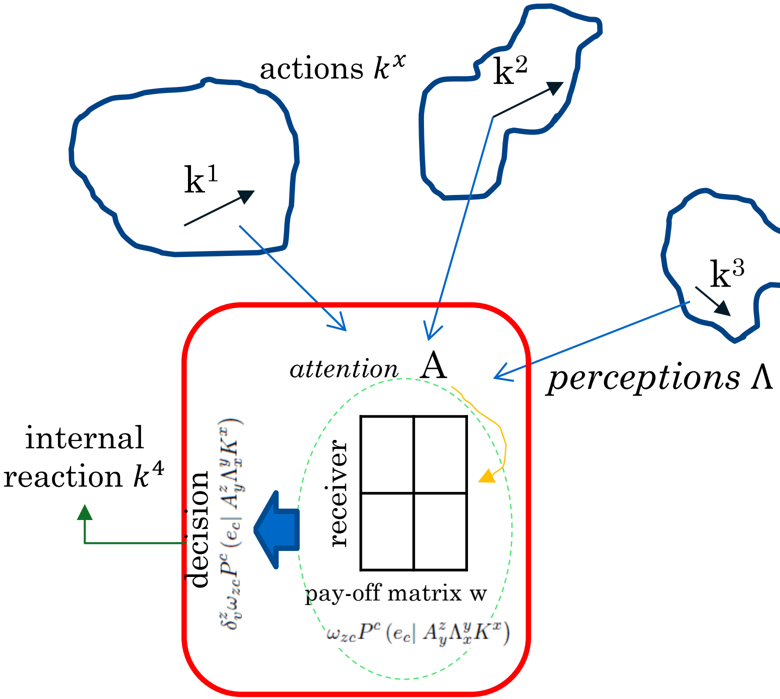
$$z = \begin{bmatrix} a & 0 & 0 & 0 \\ \alpha & b & \beta & 0 \\ \alpha & \beta & b & \beta \\ \alpha & 0 & \beta & b \end{bmatrix} \Rightarrow k = -\frac{\alpha e}{a(b+\beta)}$$

k unchanged

04

CORDS AND GAME THEORY

CORDS & GAME THEORY



$$h_{vx}\left(K^x\right) = \delta_v^z \omega_{zc} P^c \left(e_c \middle| A_y^z \Lambda_x^y K^x\right)$$

Cords based on game theory lead to IA macro-modeling in order to cover the cyber side of the CPSoS

05

CPSOS MODELING

1. collect objects used in the CPSoS $\bigoplus_i Q_i$

2. define transformations and connections necessary to make te system

$$w_{\beta\sigma} = C_\beta^q \left(F_q^i Q_{ii'} F_{q'}^{i'} \right) C_\sigma^{i'}$$

3. add couplings coming from various physics $z_{\beta\sigma} = w_{\beta\sigma} + \mu_{\beta\sigma}$

4. add cords for the cyber side : $\zeta_{\beta\sigma} = z_{\beta\sigma} + h_{\beta\sigma}$

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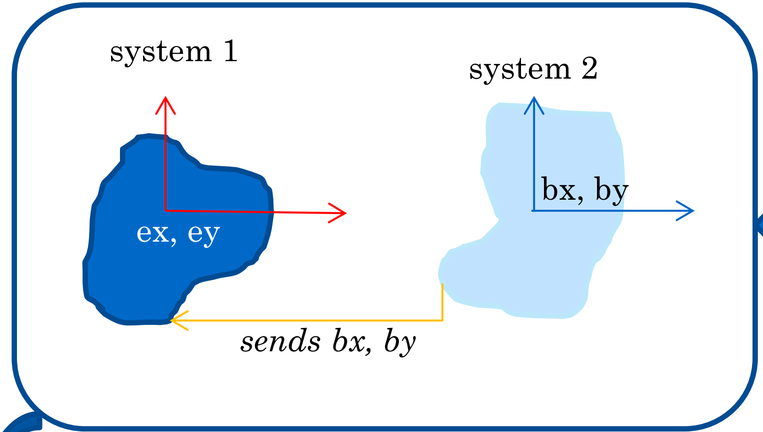
ILLUSTRATION

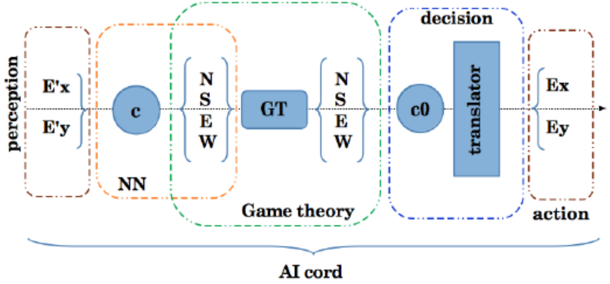


$$\zeta_n = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$\zeta = \begin{bmatrix} 1 & 0 & \mathcal{A}_{xx} & \mathcal{A}_{xy} & 0 & 0 & 0 & 0 \\ 0 & 1 & \mathcal{A}_{yx} & \mathcal{A}_{yy} & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & \mathcal{A}'_{xx} & \mathcal{A}'_{xy} \\ 0 & 0 & 0 & 0 & 0 & 1 & \mathcal{A}'_{yx} & \mathcal{A}'_{yy} \\ 1 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix}$$

	N	S	E	W
N				
S	$ea_{ij} = \left[\bar{d}_c(i,j,t) + d_\theta(i,j)\right]^{-1}$			
E				
W				

$$\begin{cases} if\ c_0 = N \Rightarrow e_y = A\left(1 - e^{-\tau p}\right) \\ if\ c_0 = S \Rightarrow e_y = -A\left(1 - e^{-\tau p}\right) \\ if\ c_0 = E \Rightarrow e_x = A\left(1 - e^{-\tau p}\right) \\ if\ c_0 = W \Rightarrow e_x = -A\left(1 - e^{-\tau p}\right) \end{cases}$$



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CONCLUSION

The xTAN method can offer:

- ❖ same capacity than bloc diagram to represent the SoS mechanisms
- ❖ intrinsic capacities to embed electromagnetic interactions
- ❖ a particular cord to take into account cyber behaviors
- ❖ a global methodology to model cyber-physical systems of systems

Works to start from class description of the system is currently runing

Thank you