

**Stigmergic Information Flow in  
Systems of Systems**

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# Outline

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- Introduction
- Information Flow among CSs
- Stigmergy
- Open vs. Hidden Channels
- Conclusion

# Emergence

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- Emergent Phenomena at the SoS level are caused by the *information flow* among the Constituent Systems (CS) of an SoS.
- It has been shown that *feed-forward* and *feed-back* information flow and the associated time delays are of particular relevance for the appearance of emergent phenomena.
- The first step in the analysis of emergence relates to the the identification of all *information channels* among the CSs of an SoS.

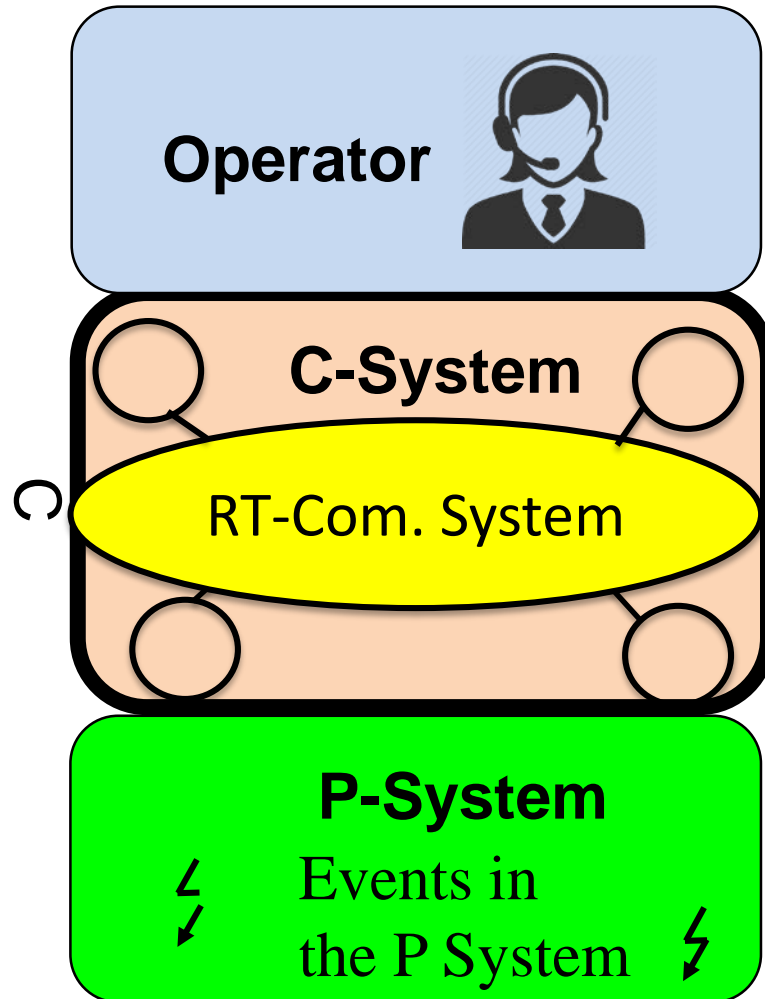
# Definition: *Emergence*

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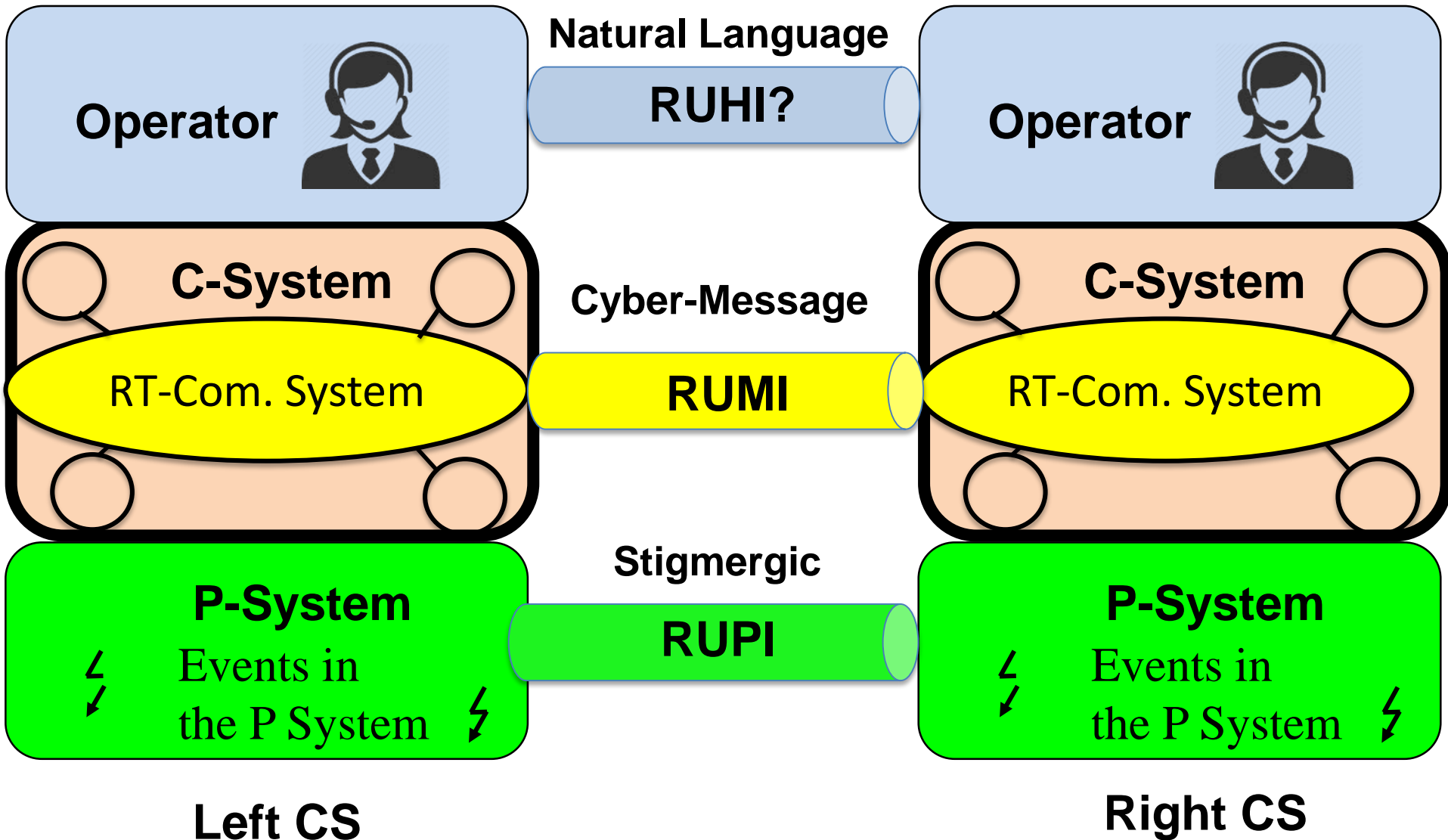
*A phenomenon of a whole at the macro-level is emergent if and only if it is new with respect to the non-relational phenomena of any of its proper parts at the micro level.*

# A CS consists of three Subsystems

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# Different Communication Channels



# Stigmergic Channels (i)

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- A *stigmergic information channel* is present if one CS acts on the environment common to many CSs, changes the state of this physical environment and another CS observes the changed state at some later point in time.
- The biologist *Grasse* introduced the term *stigmergy* to describe the indirect information flow among the members of a termite colony when they coordinate their nest building activities.
- According to the present understanding, the nearly blind ants orient themselves on the information captured by the *olfactory sense* following the intensity of the smell of the chemical substance *pheromone*.

# Stigmergic Channels (ii)

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- Whenever an ant builds or follows a trail, it deposits a greater or lesser amount of pheromone on the trail, depending on whether it has successfully found a prey or not. Due to positive feedback, successful trails—i.e. trails that lead to an abundant supply of prey—end up with a high concentration of pheromone.
- The running speed of the ants on a trail is a non-linear function of the trail-pheromone concentration.
- Since the trail-pheromone evaporates—we call this process *environmental dynamics*—unused trails disappear autonomously as time progresses.



# Traffic Flow

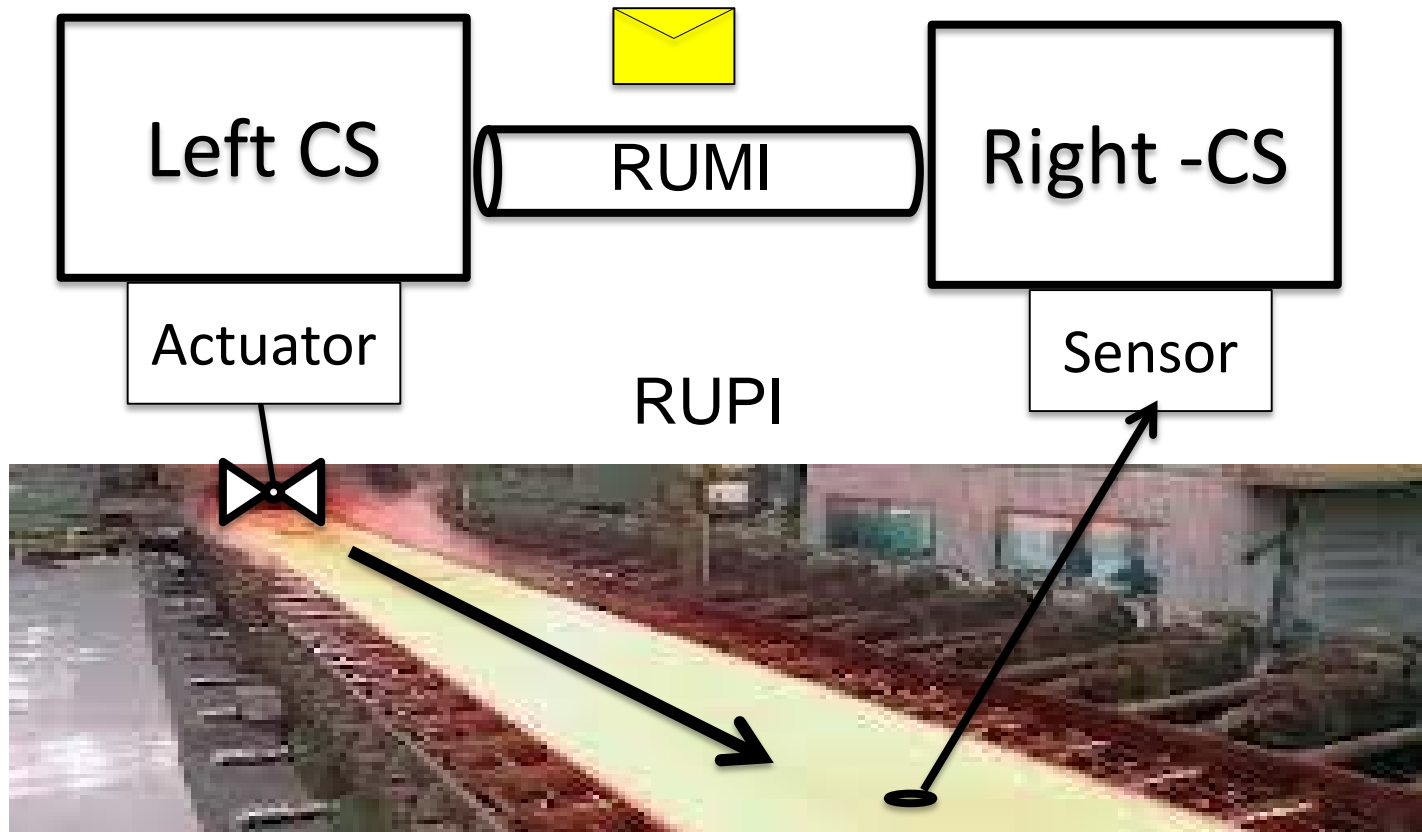
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The information flow among drivers on a busy road is mainly of the *stigmergic* type.

<b>Characteristic</b>	<b>RUPI (Stigmergic)</b>	<b>RUMI (Cyber Message)</b>
Information Type	Properties of Things	No Restriction
Inform. Transfer	Pull	Push
Tense	Present	Past, Present, Future
Observation Mode	Direct	Indirect
Observation Delay	None	Existent
Comm. Delay	Unbounded	Bounded
Source	Unknown	Known
E-Dynamics	Considered	Not Considered
Representation	Single Context	Multiple Contexts

# Hidden Stigmergic Channels



In addition to the intended stigmergic channel realized by the controlled object there can be a hidden stigmergic Channel, e.g. caused by *heat transfer*.

# *Open Channels vs. Hidden Channels in an SoS*

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	Open Channel	Hidden Channel
Message Channel	Cyber Channel (RUMI)	Human Communication (RUHI?)
Stigmergic Channel	Material Flow in Control Loop (RUPI)	Physical Side Effects

# Conclusion

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- Emergent Effects at the SoS Level can be caused by *open* and *hidden* information flow.
- In addition to the information flow across the RUPI possible *natural language information flows* among human operators and the *stigmergic information flow* via the physical environment must be identified.
- *Physical side effects* can give rise to *hidden stigmergic channels*.