TOWARDS A THEORY OF DATA FUSION IN SENSOR NETWORKS

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Fundamental Problem

FUNDAMENTAL LIMITATIONS ON DISTRIBUTED INFERENCE IN LARGE ARRAYS OF MICROSENSORS (POSSIBLE IN MOVEMENT), GIVEN CONSTRAINTS ON INFORMATION PROCESSING AT EACH SENSOR LOCATION AND CONSTRAINTS ON COMMUNICATION BETWEEN PROCESSORS.

Ideally

ONE WOULD LIKE

- SHANNON-LIKE THEORY FOR DISTRIBUTED INFERENCE ON A MOBILE SENSOR NETWORK WITH AVAILABLE COMMUNICATION OVER NOISY CHANNELS LINKING THE NODES OF A NETWORK.

Further Difficulty

INFORMATION GATHERING AND PROCESSING

DONE TO MEET OBJECTIVES SUCH AS:

DETECTION (TARGETS)

CLASSIFICATION AND TRACKING OF EVENTS

DYNAMIC TARGET TRACKING

Therefore

FOR EXAMPLE

- REAL-TIME (DELAY) ISSUES MIGHT BE AN IMPORTANT CONSIDERATION, SOMETHING INFORMATION THEORY, AS IT CURRENTLY STANDS DOES NOT HANDLE VERY WELL.

(See recent theses: A. Sahai: any time information theory and S. Tatikonda: control with communication constraints)

Furthermore

- NEED AN ABSTRACTED, HIERARCHICAL VIEW OF INFORMATION, THAT IS, INFORMATION IS NOT JUST BITS.

  REPRESENTATION OF INFORMATION

  CONCEPT FORMATION AND LEARNING

- INFORMATION PROCESSING STRUCTURE SHOULD REFLECT REPRESENTATIONAL STRUCTURE.

- NETWORK ARCHITECTURE, FAILURES, RECONFIGURATION

- SOFTWARE VERIFICATION

  THEORIES BUILT INTO VERIFIER

Many dimensions to the research program

Main Theme

robust distributed inference in a dynamical networked environment.

coding & decoding, inference, statistical mechanics of disordered systems

(Fall term: Seminar Course at mit)

What is the data fusion problem?

State of the World to be Inferred:

Given

$$(\Omega, \mathcal{F})$$

Ω: Sample Space (Structured)

$\mathcal{F}$: Set of Events

For example: $\Omega = \Omega_1 \times \Omega_2 \cdots \times \Omega_N$

and

$\mathcal{G}_i(\omega; B) \quad , \quad \omega \epsilon \Omega, B \epsilon \mathcal{G}_i \subset \mathcal{F} \quad , \quad i = 1, \ldots \mathbb{K}$

(i) For fixed $B \quad \omega \longmapsto p_i(\omega; B)$ is a random variable

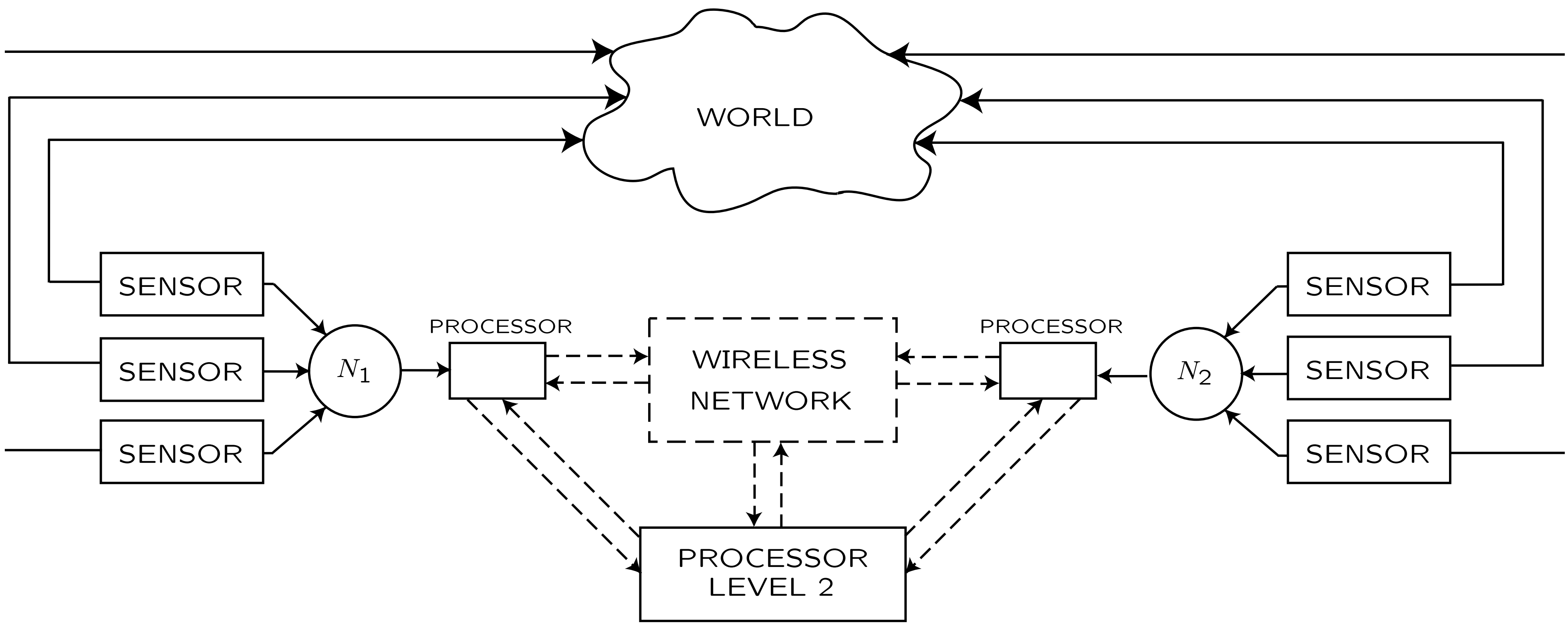
(ii) For fixed $\omega \quad B \longmapsto p_i(\omega; B)$ is a probability measure on $(\Omega, \mathcal{F})$

What is the data fusion problem?

Find all possible probability distributions $\mathbb{P}\epsilon\mathcal{P}(\Omega)$ (set of all probability measures on $(\Omega, \mathcal{F})$ which are consistent with $\mathcal{G}_i$, that is, for $A\epsilon\mathcal{F}$, $B\epsilon\mathcal{G}_i$

$$\mathbb{P}(A \bigcap B) = \int_B p_i(\omega, A)\mathbb{P}(\mathrm{d}\omega) \quad i = 1, \ldots K$$

i.e. the p_i became Conditional Probabilities.


WORLD
SENSOR
SENSOR
SENSOR
N_1
PROCESSOR
WIRELESS
NETWORK
PROCESSOR
N_2
SENSOR
SENSOR
SENSOR
PROCESSOR
LEVEL 2

The issue of architechure hierarchies at different levels of abstraction

TOP DOWN vs. BOTTOM UP PROCESSING
ROLE OF FEEDBACK

(Presentation of Maurice Chu)

ABOVE PRESENTATION IN THE CONTEXT OF TEST BED AT XEROX PARK

Architectural Issue

UNIVERSAL PART

DOMAIN SPECIFIC (DESIGNED)

CENTRALLY DESIGNED DISTRIBUTED SYSTEM vs. DISTRIBUTED IMPLEMENTATION

Theory of Interconnections

SHANNON THEORY OF DIGITAL COMMUNICATIONS AS A THEORY OF INTERCONNECTIONS

(OPEN ISSUES: SYNCHRONIZATION, ROBUSTNESS TO PROBABILISTIC ASSUMPTIONS)

CORRESPONDING THEORY IN NETWORKED ENVIRONMENT ??

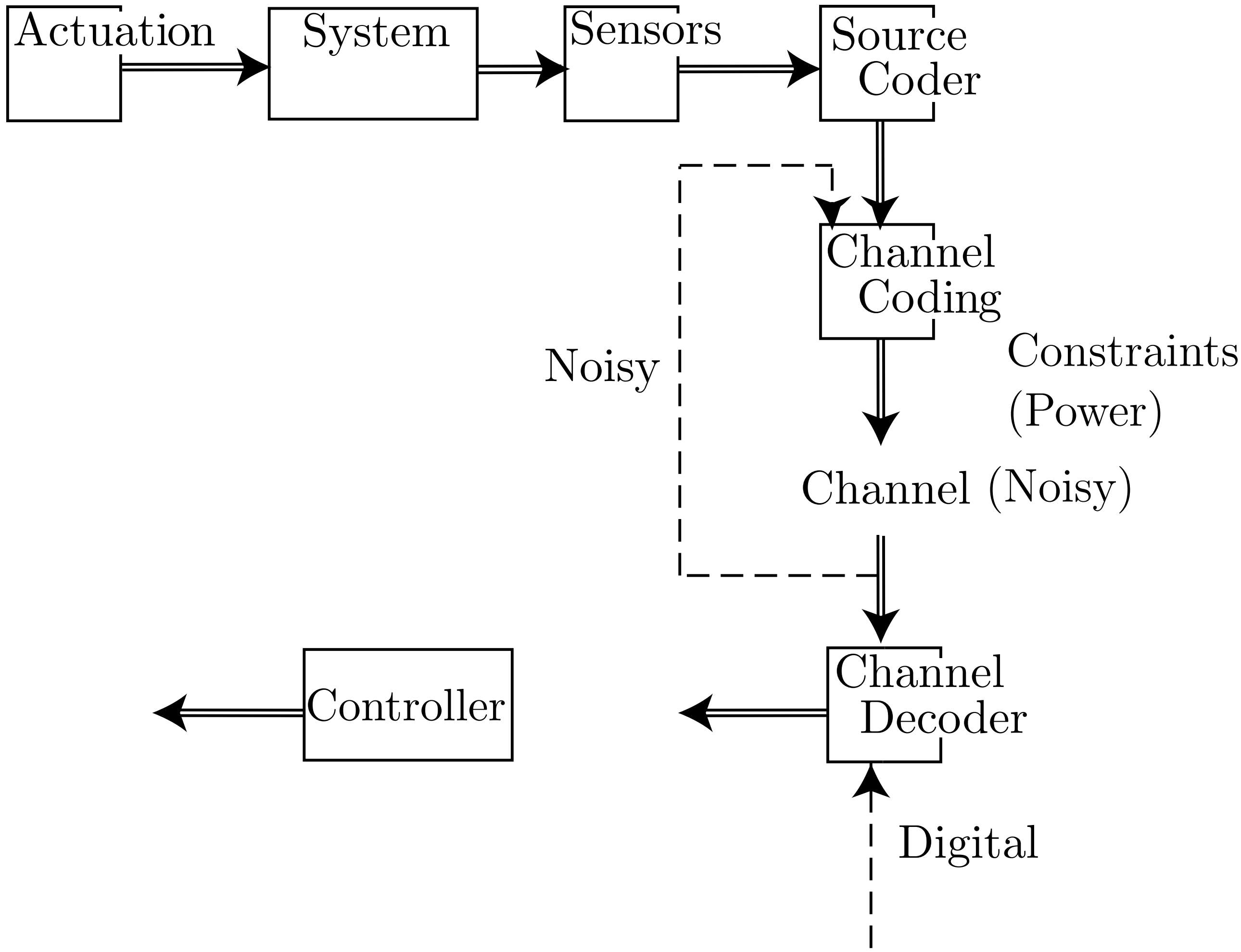
REDUCTION TO BITS ??

IN A NETWORKED ENVIRONMENT NOT JUST COMMUNICATION PROBLEMS.

DECISION MAKING IS INTRINSIC TO THE OVERALL PROBLEM

(See Presentation of P. Kumar)

COMMUNICATION & CONTROL



FUNDAMENTAL LIMITATION OF CONTROL & COMMUNICATION (SIMULTANEOUS)

SEPARATION

- COMMUNICATION & CONTROL
- SOURCE CODING

PROBLEM:

FIND ENCODER & DECODER SUCH THAT WE OBTAIN DESIRED BEHAVIOR FROM $(M_t)_{t\geq 0}$ (SOURCE) AND ITS RECONSTRUCTION $(\widehat{M}_t)_{t\geq 0}$, THAT IS:

$$\mathcal{V}_d \subseteq \mathbb{P}_{(M,\widehat{M})}(\cdot)$$

$\longrightarrow$ CONTROL PROBLEM: CAPACITY

$\longrightarrow$ INFERENCE PROBLEM: RATE DISTORTION

$\longrightarrow$ INFORMATION TRANSMISSION

$\longrightarrow$ SEPARATION THEOREM

Example of a distributed estimation & detection problem with exponential complexity

TWO STAGE DETECTION & ACTION PROBLEM

MINIMUM COST PARTITIONING PROBLEM

Correspondence Diagram

PRESENTATIONS $\Longrightarrow$ RCA'S

MITTER	RCA 2	(Fundamental Limitations Networks)
	RCA 3	(Trade-offs)
	RCA 4	(Robustness)
	RCA 6	(Coherence Reconfiguration)
KUMAR	RCA 2	
	RCA 3	
REZNICK	RCA 2	
WILLSKY	RCA 2	
	RCA 3	
	RCA 4	
FISHER	RCA 5	

CORRESPONDENCE DIAGRAM cont.

$$\text{KULKARNI} \quad \left\{ \begin{array}{l} \text{RCA } 1 \\ \text{RCA } 4 \\ \text{RCA } 5 \end{array} \right.$$

$$\text{JAAKKOLA} \quad \left\{ \begin{array}{l} \text{RCA } 4 \\ \text{RCA } 5 \end{array} \right.$$

$$\text{CHU} \quad \left\{ \begin{array}{l} \text{RCA } 3 \\ \text{RCA } 5 \\ \text{RCA } 6 \end{array} \right.$$

$$\text{WILLSKY} \quad \text{RCA } 7$$