Information Dynamics
A Fresh Look at Information
Its Properties and Implications

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What *Information* does this picture carry?

Has it changed recently?
What Information does this sequence carry?

What is the basic nature of Information?

Only Sentient entities handle it!
What is Information?

- Information is different from its representation!!
- Can have many representations
  - Are they equivalent??

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Information

- Many forms
  - Technical – Shannon
- Everyday use
- Distinction between information and its Representation
Information and Representation

Sentient Entity

Information

Perceived Reality

Representation

Information

Perceived Reality

Representation
Information versus its Representation

- No one-to-one mapping
- Representation is meaningless without a relation to the appropriate contextual information
- Must understand the relationship of the representation to the appropriate information
- Representations are transmitted across boundaries via physical means (messaging, voices, etc.)
- All typical manipulations of information are through manipulations of its representation

How is the mapping carried out?

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Perceived Reality

- All a sentient entity knows...
  - Facts
  - Figures
  - Relationships
  - Models
  - ...

- ...about
  - The environment
  - another entity or system
  - Itself
Perceived Reality

- Any local node maintains its view of the universe and other entities in the form of *Perceived Reality*

Perceived reality is based on
- Prior *Model* of the Universe and Other Entities
- Explicit information received and processed
  - Explicit information is processed to integrate it with the perceived reality
  - This integration is based on the model of the universe
  - Information may change the model

- All actions are initiated using the knowledge of the perceived reality

- *All systems have been bootstrapped with information to start its “life”*
Models

- Abstraction of an entity or a system.
- Contains properties and relationships believed to be true.
- One part of an entity’s perceived reality is the model of another entity.
- Constantly refined by information:
  - New, Refuting, Removing, ...
Perceived Reality

- When a message is received
  - Its contents are converted into information based on the current perceived reality
  - That information is assimilated into the current perceived reality

- A message (representation) can not be converted into information unless the perceived reality contains the means for reverse mapping
  - Language – Symbols - ...
What is Information?

- **Information Entity**

- Information has many
  - interrelationships
    - attributes
    - properties

- Interrelationships are information also

- Such interrelationships exist whether they are enumerated/identified or not
Information and Representation

- From Information to Representation:
  - Some facts will not be retained!
  - Loss of relationships!

- Manipulation:
  - Informational
  - Representational
What is Information?

- Information is handled by Sentient Entities
- Its representations can be handled by machines
- Machines only manipulate representations of information.

\[ 2 + 3 = 5 \]
Information and Representation

Operational Cycle:

1. Information → Operation
2. Operation → Information
3. Perceived Reality
4. Representation
5. Operation
6. Representation
What Is Information?

- It is a property /description/characteristics of something
- That something may be another piece of information
  - An object – Physical, logical, virtual, conceptual – group
  - An action
  - A trigger
  - A relationship
- Significance of Information is its interrelationships
  - May be direct or indirect
  - Exist whether enumerated or not
  - May be static or dynamic

Typically retain only small amount of information considered relevant in any system
Nature of Information

- Quantifiable
  - Only in the context
    - Temperature in this room
    - Scale
    - Accuracy
    - Time it was recorded
    - Who took it
    - What instrument was used - precision

- Non-quantifiable
  - Most of the information we deal with is of this type
Information Representation

- Representations are essential to store, move, or process information
- Capture only some aspects/views/projections of information —
  - A good system designer carries other aspects in her head.
- Example: Data Structure
  - Contains not only representation of some quantities but also of some relationships

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Information Representation

- Use – Requires associating meaning to it
  - Meaning can only be assigned in context

- Context
  - Integer between 50 and 100
  - Represents temperature in this room in degrees F.

- If both sides understand the context
  - Only need representation of integer number

- If not
  - Common understanding may be English
  - Include description along with the temperature value
Information Representation

- Algorithm
  - Sequence of steps
    - Have common understanding of elemental steps
    - Depend on the way they are expressed
      - Machine instructions
      - Higher level language
      - Pseudocode
      - ...
Multi-step Processing
Explicit and Implicit Information

- **Explicit**
  - Conveyed explicitly through messages etc.

- **Implicit**
  - Derived from explicit and the current knowledge of its relationships - *perceived reality - models*
  - Requires *processing*
    - Spending Resources: Time and Energy
  - Can be different for different agents!!

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Meta-Information

- Ontology

- Levels of Meta Information?
What can we do with information

Using Information requires **ACTION**
- Create/capture
- Store
- Move/Retrieve
- Use
  - To derive implicit information – making it explicit
  - To determine some other action to be taken (Choice)
  - To activate a physical operation (output)
Storage of information

- In order to store any information which is explicit we need a representation for it.
- In order to use it as information we need to retrieve it from storage.
- A representation of information suitable for storage may not retain many interrelationships.
  - On retrieving
    - some may be recalculated
    - some may be lost forever
    - In particular, information relating to time will be lost unless time stamping is done.
- Storing/Retrieving of Information are actions.

Note that any and all actions generate lot more information than can be captured.
Movement of information

- Only explicit (represented) information can be moved from one location to the other.
- Information to be moved must be in a representation which is understood and can be interpreted by the sender and the receiver.
- The understanding can come from explicitly represented agreements (which in turn require conventions - Protocols).
- It must be storable.
- Requires an action.
Information movement infrastructure

- Network
  - Provides the ability to move info from location x to y
  - Who initiates the move
    - When
    - Why
- How does y know that x has some information it needs?
- How does x know that y needs that information?

- Knowledge about where what information is?
  - Search Engines !!
    - Have to know where the search engine is and how to access it.
Implications of Information Movement

- Moving information from location \( x \) to location \( y \) takes time \( t_{xy} \).
- At \( y \) we can only get information from \( x \) which is at least \( t_{xy} \) old.
The perceived reality at any location **CAN NOT** be the same as the actual reality at any remote location of the global reality
- Due to the transmission and processing delays
- It is not sufficient to receive the information
- It must be interpreted and processed to integrate it with the current perceived reality
- Perceived reality at a location may be **consistent** with global/remote reality but cannot be the same
- We can never have a complete model of another entity:
  - models abstract knowledge
Due to finite precision of measurement and representations we can never have complete and precise knowledge of any quantifiable information.

We deal with this uncertainty all the time !!!
Value of Information

- Implicit understanding of the value
- Is entity/agent specific
- Use in selecting – deciding among options for processing and taking action
- Value of information changes with time
  - Different for each agent
  - Depends on his perceived reality
  - Can not assign a fixed ordinal scale to the value
Value of Information

- Value may be captured by uncertainty models

- Example – queue length at a router
  - The knowledge of the queue length at time t may be precise
  - The knowledge at a later time given the value at t will have a variance which will increase with time
  - When we want to know the value of queue length from some other location, the information movement delay increases the variance
Information Fusion

Given Multiple observations –

- How to integrate them into one “view”

- One view may contain multiple options / likely scenarios
Capture of Information

- Two mechanisms
  - Observation – Through direct or indirect observation/ monitoring/measurement
  - Processing of info – Make implicit information explicit
    - To enumerate interrelationships
    - To make deductions
    - To make inductions
    - Using models

- Example: Mathematics
  - A set of interrelationships with a description of when they apply
  - A framework for deductions and inductions to add to the information base
  - Analytical Results => defined interrelationships and descriptions of applicability
Action

- Physical Action
  - Results in physical manipulation

- Non-Physical
  - Thinking
    - Exploring inter-relationships
  - Processing within a computer

- All Actions take time and consume energy
- Begins with an information trigger!
- Usually done with respect to an event.
Action

- Requires Processing
- Starts under the control of "Trigger"
- Needs
  - Processor
    - Possibly other resources
    - For some time
  - At a location
  - Information as input

- Outcome
  - Additional Information
    - Explicit from Implicit
  - Trigger(s)
  - Storage
  - Movement
  - Physical results
    - Commands to actuators
Three Levels

- Information
- Represented Information
- Physical
Types of Actions

- Make implicit information explicit
- Carry out interpretation/storage/movement of information
- Carry out a physical action by issuing a command to a physical processor
- Transform some information into some trigger which is used to control some later action
Trigger

- Required for carrying out an action at a particular time/under some conditions
- Defines
  - What action, where, using what resources, at what time or under what conditions (priority, precedence etc.)
- Based on information/location/time/value
- Requires processing to convert information into a Trigger
- When relationships are fixed – hardwired design – Design time Trigger
- When relationships are dynamic trigger has to reflect it
Large Complex System

- A collection of $N$ entities capable of carrying out certain operations
- Has a mission
- Physical resources which can carry out the actions
  - At various locations
- Mechanism for moving information (communication)

- Design Carried out at Information Level
Coordination: A Distributed System

- Information-centric view
- Many interacting autonomous agents
  - Who needs what information at what time
    - Why
    - How will he use it
  - Who has that information at what time
  - How to get the right information at the right place at the right time
- Most algorithms – mechanisms for such movement of information with respect to elemental processing capabilities assumed
Role of Time

- Do we need a global/universal clock?
- What type of time is appropriate for Information Dynamics?
  - Absolute Time with a Counter (though it has a value relative to a starting point)
  - Relative Time through Causality
Consistency

- How can coordination take place without consistency of models each entity has from one another?
- Models between communicating entities must be consistent and accurate enough
- Who has the responsibility to fix broken models?
- Do models follow a set of rules?
  - Logically, relationally, or operationally.
Awareness

- In order for entity A to be aware of entity B, entity A must have a model of entity B.
- Entity B need not have a model of entity A.
- Being aware does not mean having complete knowledge of another.
Levels of Abstraction

- Any massively complex system has to be viewed at an appropriate level of complexity
  - Information with right degree of detail
  - Only relationships of interest and their connections of interest are retained
Planning

- Requires knowledge about future
  - Using Models
  - Estimates
    - Accuracy
    - Confidence
- Knowledge of Dynamics
  - Expected changes over time
Example – Mutual Exclusion Problem

- N Agents - Cooperative
- Any agent can enter its CS if nobody else is in its CS
- Check if anybody is in its CS
  - If not – enter
  - If yes – wait and try again
- Each action takes time
  - State of agents can change in that time

Entry
CS
Exit
Non – CS
LOOP
Mutual Exclusion Problem

- How to know the state of all other agents
  - Shared memory model
  - Distributed – through messages

- Shared Memory Model
  - Set up a mechanism for sharing of state information
    - Semaphore
  - Delay
    - Atomic action
  - Define checking mechanism

- Distributed
  - Messages

- Algorithms vary in terms of the implications of messages and their meaning

- Simplest – Ask everybody for permission and enter when received from everybody

- How to process a permission request?
Example - Security

- Key – part of “perceived reality”
- How does B know which key to use?
- Public Key encryption
Example – Link State Routing

- Each node measures delays
- Periodically send the measured delay to every other node
- Determine route as the minimum delay path from source to destination

- Need delay when packet gets there not what it was
- Estimate of future delay rapidly moves towards the steady state values
- IF Steady State values are known
  - Reduce communication
  - Improve routing

- Demonstrated through implementation/simulation

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Information-centric Design

- Having right information at the right place at the right time
- Explicitly take into account the time dependent aspect of information
- Explicitly take into account the value of information
- Explicitly take into account implicit information
- Organize/design system based on the dynamics of information requirements
Rover Technology

- Context-aware computing platform
  - Location
  - Time
- Self-describing Information Representations
- Services/actions depend on context
Rover Technology

Rover Clients

Comm Server

Rover Server

PPMP – PinPoint Mobile Point

PPRP – PinPoint Reference Point

DB Server

Location Server

Web Server
Rover Technology

- Designed to address issues in
  - Enterprise Applications
  - Command and Control Applications
  - Pervasive Computing
  - Sensor Networks
  - ...

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Rover Network Diagram

Rover Server accesses internet services as a proxy for Rover Clients, with Services including (with support for caching):
- Yahoo!
  - News and Web Searches via REST
  - Weather RSS Feeds
- UMD Wireless Network
  - AV Williams Building, 3rd and 4th Floors
  - Unit 1
  - Unit 2
  - Units inform their position, performs tagging operations, and utilizes other services.
- MINDLab Network
  - 8400 Baltimore Avenue
  - Watcher 1
  - Listens for position activity, performs tagging operations, and utilizes other services.
- UMD/CS Unsupported Private Network
  - AV Williams Building, Room 4160
  - Watcher 2
  - Listens for position activity, performs tagging operations, and utilizes other services.
- UMD/CS Unsupported Public Network
  - AV Williams Building, Room 4160
  - Mitigates Rover Services Between Rover Clients Including:
    - User Position Notification
    - Map Tagging
    - Text Chat
    - Internet Services
- The Internet
  - Rover Server accesses internet services as a proxy for Rover Clients, with Services including (with support for caching):
    - Yahoo! News and Web Searches via REST
    - Yahoo! Weather RSS Feeds
Uses of Information Dynamics

- Framework for
  - Approaching system designs
  - System Analysis
    - Given a design determine
      - All Information Dynamics – Explicit and Implicit
      - Decision Structure
      - Actions
  - System Synthesis
    - Outcome required
      - Processing/Action needed
      - Information needed
Questions???