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Information-Velocity Metric for the Flow of Information through an Organization:

Application to Decision Support

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Presentation Topic Outline

- Information flow
- Information velocity, v(info)
- Relationship between information and power
- Reducing uncertainty in decision making
- Can we measure v(info)? Yes and No
- Information-flow model for decisions support
- Can we measure factors the influence v(info)? Yes
  - Direct measures
  - Causal measures
  - Effects measures

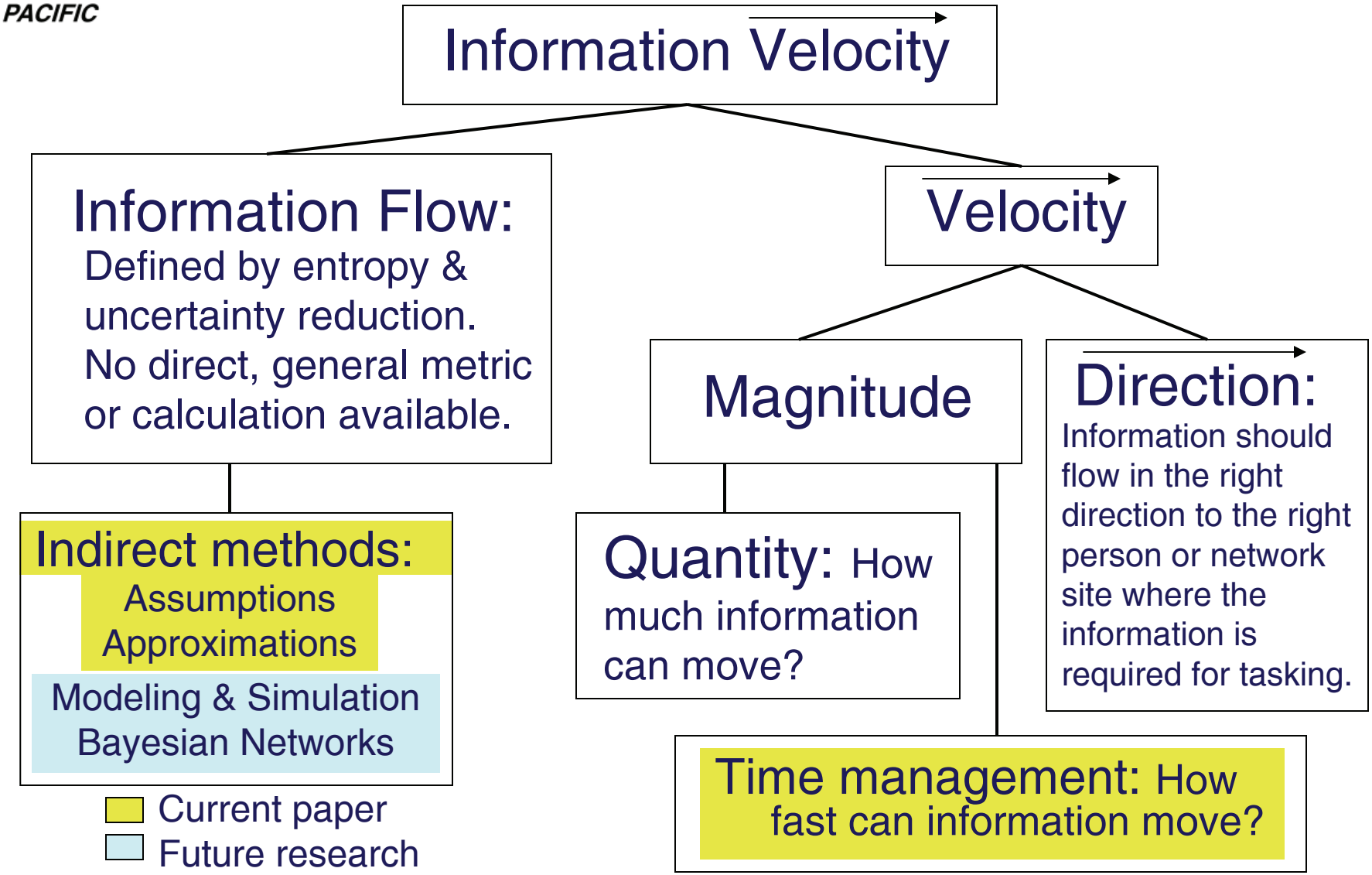
Information Flow

- p = Information flow, summarized as the difference between in conditional entropy, $\mathrm{H}(h|l)$, of variable, h, before the process started given the variable l_1 and after the process finished, given the variable l_2.
- $$p = \mathrm{H}(h|l_1) - \mathrm{H}(h|l_2)$$
- $\mathrm{H}(h|l_1)$ is high because many alternative COAs are consistent with sparse data.
- $\mathrm{H}(h|l_2)$ is low because the few alternative COAs are consistent with the new data set.
- p corresponds to the reduction in uncertainty that results from the receipt of new data.
- p depends on the specific task.
- p has no explicit time dependence.

Information Velocity

- **v (info)** is defined as the speed and direction of information flow, p.
- First time derivative of the information flow.
- Explicitly a vector quantity.
- $\mathbf{v\ (info)} = dp / dt$
- $= d\ \mathrm{H}(h|l_1) / \mathrm{dt} - d\ \mathrm{H}(h|l_2) / \mathrm{dt}$
- For example h = COA, l_2 = a new data set.
- Depends on the task tractability, T_y, & the ***power*** of information to reduce uncertainty.
- An important topic of research aimed at reducing uncertainty in time-constrained decision making scenarios as fast as possible.

Taxonomy of Information Velocity



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How Is Information Related to Power?

- 2nd law of thermodynamics, $dS = dU_{rev} / T$
  - S = entropy, U = reversable heat, T = temperature
- Infodynamic analog: $\delta H(h|l) = \delta W / T_i$
  - W = work, T_Y = task tractability, assumed constant at given entropy
- $\delta W = F\ dX = J\ (d^2X/dt^2)\ dX$
  - X = distance, J = information (analog of mass).
- $dH(h|l) / dt = (J / T_i)\ (d^2X/dt^2)\ dX/dt$
- Combining these equations with p yields

$$\boxed{v(info)} = d/dt\{(\tfrac{1}{2} J X_d^2)_1 / T_{Y1} - (\tfrac{1}{2} J X_d^2)_2 / T_{Y2}\}$$

where $X_d = dX/dt$

- Energy = $\tfrac{1}{2} J X_d^2$ $\boxed{\text{Power}} = d/dt\ (\tfrac{1}{2} J X_d^2)$
- Take away from the derivation: **The rate at which information travels is proportionate to power.**

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Can We Measure Information Velocity?

- Yes. In modeling-and-simulation experiments.
  - Where we can define and control all the variables.
- No. Even with many assumptions, v(info) is too hard to evaluate in practice because:
  - The nature of data interactions is not always known.
  - Pedigree metadata elements may not be available.
  - The data sets may be incomplete.
  - Data and pedigree metadata are time dependent.
  - Data distributions may not be Gaussian.
  - The form of $\mathbf{H}(h|l_2)$ may be unknown.
  - Time constraints preclude detailed enough data analyses in command centers.

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Can We Measure Factors that Influence Information Velocity?

- Yes. Focus on practical time management in command centers using the following metrics:
  - Direct measures
  - Causal measures
  - Effects measures
- Consider a decision-making process model of time management in organizations in general with applications to command centers
- This model includes:
  - Measures of time spent on various tasks
  - Visibility of information
  - Empowerment of people
  - Direct, causal, effects metrics as unitless indices

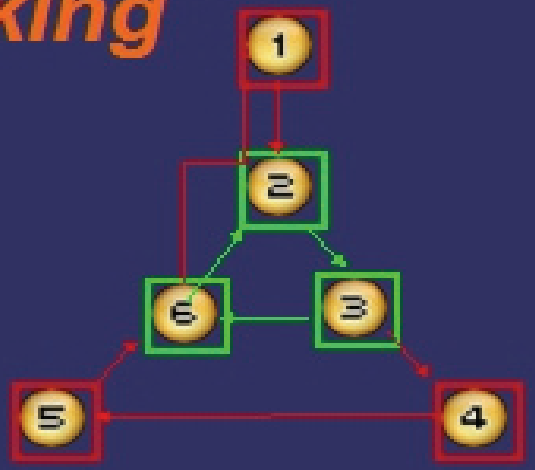
Information Flow Model for Decision Support

Example

States of Info Mgmt for Decision-Making

MM

- State 1: Gather Needed Info
- State 2: Evaluate
- State 3: Make Decision/Assessment
- State 4: Prepare Assessment Product
- State 5: Present Assessment
- State 6: Receive Feedback



= "Inner Loop" where Decision-Makers Have The Info They Need
- Evaluating, Deciding, Observing

= "Outer Loop" where Decision-Makers Don't Have Info They Need
- Gathering, Preparing, Presenting

Ideal use of time = Stay in the Green Triangle
- *cycle as rapidly as possible*
- *spend as little time as possible in each state*
- *avoid entirely red states 1, 4 and 5 which are the mechanics of getting info, preparing info, presenting info*

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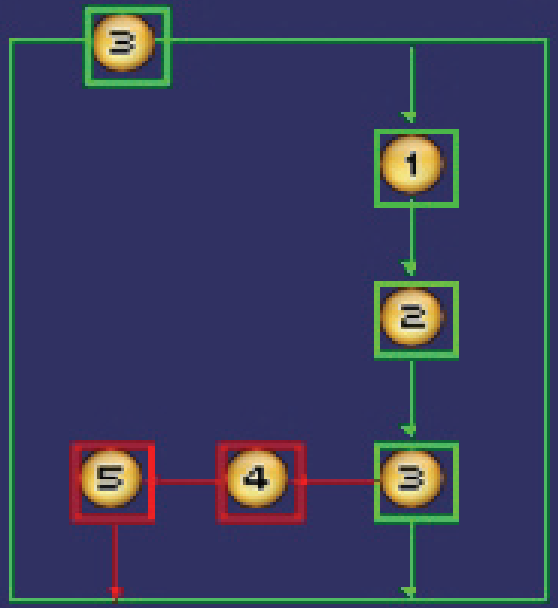
Information Flow Model: Expanded Decision Substates

Example

Expanded States of Info Mgmt for Decision/Assessment

- State 3: Make Decision/Assessment
  - Substate 1: Personal Objective Assessment (all things equal)
  - Substate 2: Personal Subjective Assessment (all things equal)
  - Substate 3: UnFiltered Decision
  - Substate 4: Applying Cultural & Other Non-Substantive Filters (cultural acceptance, what answer do "they" want, what answer is easiest, what answer might get me in trouble, etc.)
  - Substate 5: Filtered Decision



Ideal use of time = Avoid the Non-Substantive Filtering Red States
- red states represent delay in info flow due to inappropriate filtering
- red states represent a decision where individual is modifying answer for non-substantive reasons & pressures

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Assumptions in the Model & Metrics

Metrics for time management in decision making depend on the following assumptions.

- Better time management increases v(info).
- States and substates described in Figures 1 and 2 are independent of each other.
- Time spent in green states increases v(info).
- Time spent in red states does not increase v(info).
- Decision makers have the information they need in green states.
- Decision makers can define start and end times for entry and exit of various states.

Direct Measures

- **IVMDirect = Tg / (Tg + Tr)**
- **Tg** = time spent in green states
  - Considered productive activities
- **Tr** = time spent in red states
  - Considered unproductive activities
- Advantages of **IVMDirect**:
  - Time is an important factor in velocity.
  - Simplicity
  - Does not depend on causes and effects.
- Disadvantages of **IVMDirect**:
  - State boundaries are not always clear.
  - Red states may contribute to uncertainty reduction.
  - All necessary info may not be available in green states.

Causal Measures

- $$IVMCausal = \frac{Min\ (Vi, Vy, Ep)}{Max\ (Hh, Pcr, Bc)}$$
- **Vi** = visibility of information and decisions
- **Vy** = visibility of decision maker and metadata
- **Ep** = empowerment of people to increase v(info)
- **Hh** = amount of human-to-human comms
- **Pcr** = level of pressure, personal & cultural risk influencing the decision maker
- **Bc** = level of barriers to rapid, concise, honest communication
- Numerator: select smallest value of **Vi, Vy, Ep**
- Denominator: select largest value of **Hh, Pcr, Bc**

Effects Measures

- $IVMEffects = < N_D > < Q_D > < S_D >$
- $< N_D >$ = Average number of decisions per unit time
- $< Q_D >$ = Average estimated quality of decisions
- $< S_D >$ = Average level of satisfaction of the individual with the rate of uncertainty reduction

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General IVM Metric

$$IVM\% = \{ (Q3\% + Q4\% + Q5\%) / 3 - Q1\% - Q2\% + 100 \} / 2$$

- **Q1** What percentage of your day do you spend in meetings, reading and writing e-mail, talking on the telephone, in teleconferences, and in other forms of conversation and communication with others?
- **Q2** What percentage of your day do you spend preparing products intended for sharing information, eg. preparing briefing slides, reports, agendas, minutes, and completing forms and logs?
- **Q3** What percentage of what people are doing in your organization is important and relevant to you and your assigned tasks?
- **Q4** What percentage of what others decide is important across your organization or enterprise? What percentage of what others decide is visible and easy for you to understand on a daily basis? (Use a single percentage.)
- **Q5** What percentage of what you decide is important is visible and appreciated across your organization or enterprise daily?

IVM Measures Are Unitless Estimates

- **IVMCausal** $= \dfrac{\text{Min (Vi, Vy, Ep)}}{\text{Max (Hh, Pcr, Bc)}}$
- **IVMDirect** $= Tg / (Tg + Tr)$
- **IVMEffects** $= \langle N_D \rangle \langle Q_D \rangle \langle S_D \rangle$
- **IVM%** $= \{ (Q3\% + Q4\% + Q5\%) / 3 - Q1\% - Q2\% + 100 \} / 2$
- All variables in IVMCausal can be estimated on a scale of 1 to 10
- IVMDirect is a ratio of times so units cancel out.
- $\langle N_D \rangle$ = integer
- $\langle Q_D \rangle$ & $\langle S_D \rangle$ - estimated on a scale of 1-10
- IVM% depends only on percentages.

Limitations of the Methodology & How to Modify the Approach

- IVMDirect does not account for the uncertainty before and after the information was passed.
  - IVMDirect could be high and still not reduce uncertainty.
- IVMEffects depends on subjective estimates of decision quality & user satisfaction.
- The ability to count decisions to calculate IVMEffects depends on the a subjective estimate of where one decision ends and another begins.
- An approach that combines IVMDirect, IVMCausal, IVMEffects, and/or IVM% may be more accurate and useful than any single metric.
- Changes in metrics may prove more useful than any single measurement.

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Ongoing and Future Research

Ongoing

- The metrics need to be demonstrated and validated in studies, surveys, experiments, and observations.
- Explore the behavior and performance of the metrics in a modeling-and-simulation environment
- Investigate how the variables in the metrics interact and correlate with each other.

Future

- Determine ways to use the metrics in exercises and in systems development for command and control.
- Research useful ways to normalize, weight, and combine the metrics for an optimal, single value result.
  - IVMDirect, IVMCausal, IVMEffects, IVM%.
- Compare the result of a combined metric to the results of individual metrics.

Conclusion

- Concept of information velocity combines the notion of information flow and direction with time dependence.
- Theoretical development explains the relationship between entropy, uncertainty reduction, information flow, information velocity, and time dependence.
- A decision-making model that is focused on time management divides the decision process into various states that a decision maker will experience.
- Direct, causal and effects-based measures were introduced to provide metrics to estimate factors that affect information velocity.
- Goal: Support creative, agile decision-making.

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Backup information

Uncertainty Reduction Depends on Data, Pedigree Metadata, and Data Fusion

- Assume $\mathbf{H}(h|l_1)$ is large compared to $\mathbf{H}(h|l_2)$
- Minimize $\mathbf{H}(h|l_2)$ (max uncertainty reduction)
- $\mathbf{H}(h|l_i)$ depends on multiple data elements, l_i
- The importance of each l_i depends on the pedigree metadata, m_i weighting factors.
- To minimize $\mathbf{H}$,

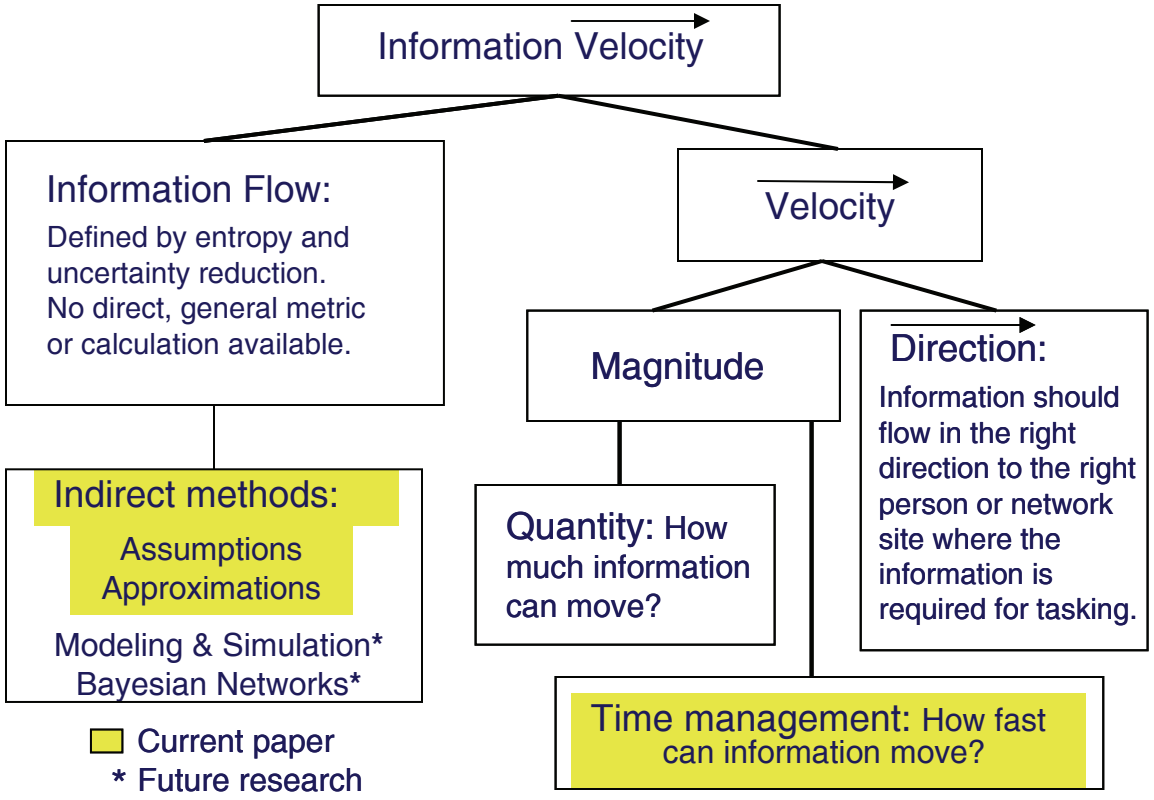
$$\nabla\, \mathbf{H}(h|l_i) = 0 \quad \text{and} \quad d^2\mathbf{H}(h|l_i) / d l_i^2 > 0$$

- Uncertainty reduction depends on 2-, 3-, and… n-way fused data. Example: l_2 data set.

$$l_2 = \{ \{l_{i\,2}\, m_{i\,2}\}, \{ l_{a2}\, m_{a2}, l_{b\,2}\, m_{b2}\},$$
$$\{ l_{a2}\, m_{a2}, l_{b\,2}\, m_{b2}, l_{c\,2}\, m_{c2}\},\ldots\{ l_{a2}\, m_{a2} \ldots l_{n\,2}\, m_{n2}\}\}$$

- In general, l_2 is too difficult to evaluate during the timeframe in which a decision must be made.

Taxonomy of Information Velocity



Metrics in Time Management

$$\nabla$$

$$H(h|l_i) = 0 \tag{12}$$

$$\nabla$$