Stochastic Routing

Routing Area Meeting

IETF 82 (Taipei)

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Routing

- Topology modeled as graph $G = (V,E,A)$
  - V: vertices and E: edges
  - A: set of attributes associated to each edge $e \in E$, e.g., residual capacity c, delay d, loss l, etc.
- Consider set $(s_1,t_1), \ldots ,(s_k,t_k)$ of i src-dst pairs
  - Associated to each pair (s_i,t_i): demand with known non-negative value v_i and size r_i
- **Routing problem**
  - Find for each unrouted demand (s_i,t_i) a routing path from s_i to t_i for it that maximizes the value of these demands without violating edge attributes
  - Adaptive routing: routing decisions depend on the instantiated sizes of the previously routed demands

Stochastic Routing

- **Stochastic routing problem** in which one or several of the parameters are not deterministic
  - **Demands size** are stochastic: probability distribution is specified for the demands
  - **Delay** to move between nodes are random variables
  - **(Simultaneous) failure** are randomly distributed according to time and space

Key Challenge: routing information and decision-making

- As in any other stochastic problem, a key issue is: "How do the revelation of information on the uncertain parameters and decision-making (optimization) interact ?"
  - When do values taken by the uncertain parameters become known ?
  - What changes can each router (must each router) make on prior-routing decisions on basis of newly obtained information ?

    => How to make correct local decisions?
    - Each router must know *something* about global state (inherently large, dynamic, and costly to collect)
    - A routing protocol must intelligently summarize relevant information

Modeling Paradigms (1)

- Real-time optimization (re-optimization)
  - Assumption: information is revealed over time as traffic follow their assigned routes/paths (also referred to as dynamic stochastic routing)
  - Operation: routes are created piece by piece on the basis of the information currently available (at each node)
  - Approach: dynamic programming

Modeling Paradigms (2)

- A priori optimization
  - A solution must be determined beforehand
  - This solution is "confronted" to the realization of the stochastic parameters in a second step
- Approaches
  - **Chance-constrained programming**: relies on the introduction of probabilistic constraints

    Pr{total demand assigned to route r ≤ capacity } ≥ 1-α
  - **(Two-stage) stochastic programming with recourse**
  - **Robust optimization**: uncertainty is represented by an uncertain parameter vector that must belong to a given polyhedral set (without any probability defined) together with, e.g., lower/upper bound for each demand and upper bound on total demand
  - "Ad hoc" approaches

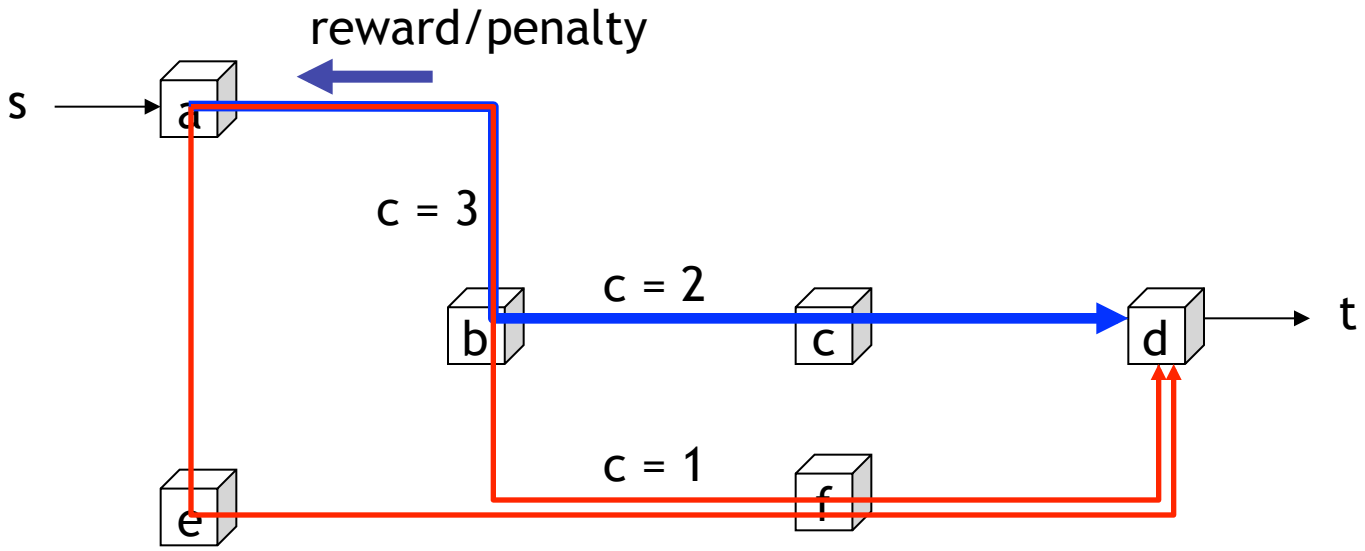
Learning-based Stochastic Adaptive Routing

Reinforcement learning (RL)

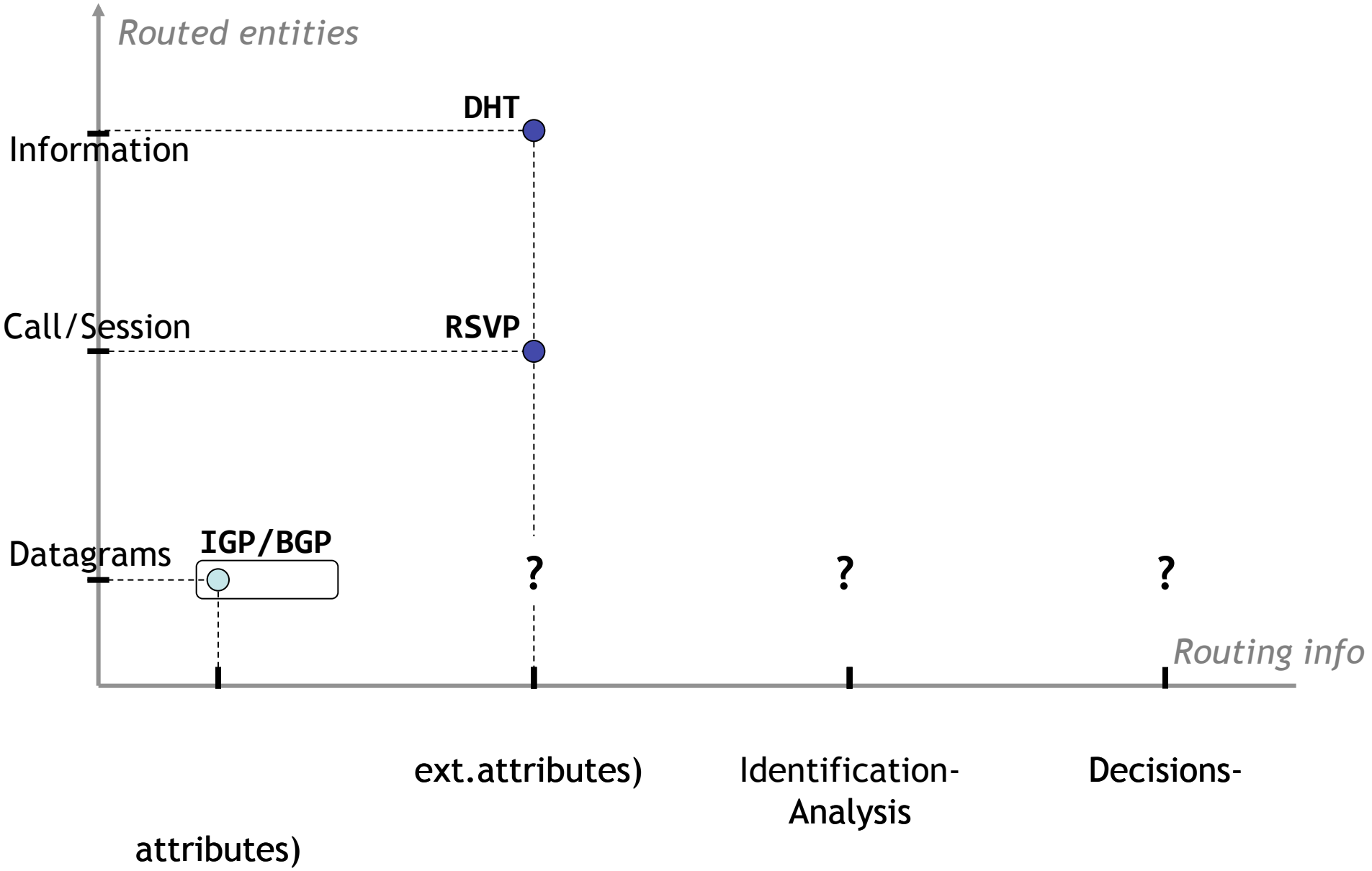
- Objective
  - Learn what to do--how to map situations (deduced from feedback from the environment) to actions--so as to maximize a numerical reward signal
  - Learner is not told which actions to take, it must discover which actions yield the most reward by trying them (note: actions may affect not only the immediate reward but also the next situation and, through that, all subsequent rewards)
- Characteristics
  - Trial-and-error search
    - Learn from interactions: obtain examples of desired behavior that are both correct and representative
    - Trade-off between exploration and exploitation
  - Delayed reward

Learning-based Stochastic Adaptive Routing

- **Routing problem** multi-agent RL problem
  - Individual router ≡ (learning) agent which adapts its routing decisions according to rewards/penalty based on
    - Global parameters
    - Non-local parameters (distribution)
    - Local parameters (determined by local observations)



Routing Space



adage
computer programmer Melvin Conway
who introduced the idea in 1968:

"...organizations which design systems ... are constrained to produce designs which are copies of the communication structures of these organizations."