Incentives and Internet Algorithms

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Outline

- Motivation and Background
- Example: Multicast Cost Sharing
- Overview of Known Results
- Three Research Directions
- Open Questions

Three Research Traditions

- Theoretical Computer Science: complexity
  - What can be feasibly computed?
  - Centralized or distributed computational models
- Game Theory: incentives
  - What social goals are compatible with selfishness?
- Internet Architecture: robust scalability
  - How to build large and robust systems?

Different Assumptions

- Theoretical Computer Science:
  - Nodes are *obedient*, *faulty*, or *adversarial.*
  - Large systems, limited comp. resources

- Game Theory:
  - Nodes are *strategic* (selfish).
  - Small systems, unlimited comp. resources

Internet Systems (1)

- Agents often autonomous (users/ASs)
  - Have their own individual goals
- Often involve "Internet" scales
  - Massive systems
  - Limited comm./comp. resources
- *Both incentives and complexity matter.*

Internet Systems (2)

- Agents (users/ASs) are dispersed.
- Computational nodes often dispersed.
- *Computation is (often) distributed.*

Internet Systems (3)

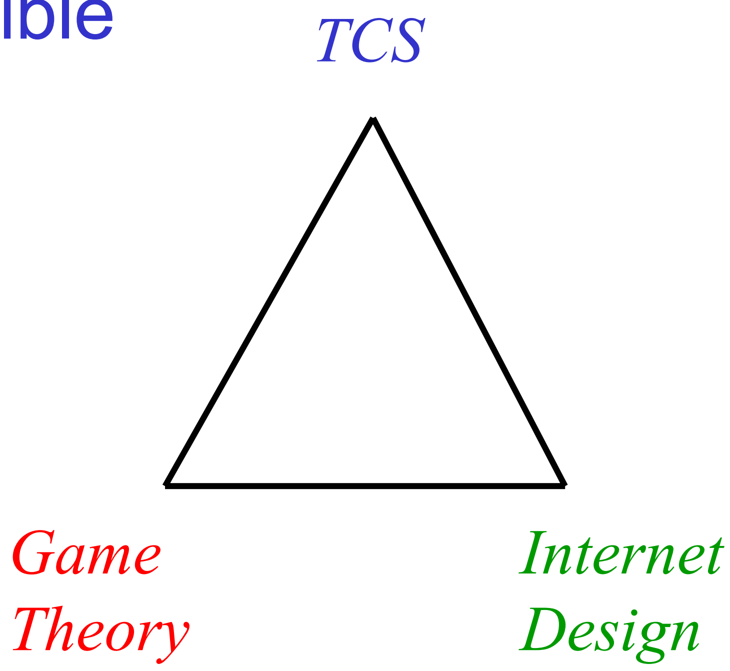
- Scalability and robustness paramount
  - sacrifice strict semantics for scaling
  - many informal design guidelines
  - Ex: end-to-end principle, soft state, *etc.*

- *Computation must be "robustly scalable."*
  - even if criterion not defined precisely
  - *If TCP is the answer, what's the question?*

Fundamental Question

What computations are (simultaneously):

- Computationally feasible
- Incentive-compatible
- Robustly scalable



Game Theory and the Internet

- Long history of work:
  - Networking: Congestion control [N85], *etc.*
  - TCS: Selfish routing [RT02], *etc*.

- Complexity issues not explicitly addressed
  - though often moot

TCS and Internet

- Increasing literature
  - TCP [GY02,GK03]
  - routing [GMP01,GKT03]
  - *etc.*
- No consideration of incentives
- Doesn't always capture Internet style

Game Theory and TCS

- Various connections:
  - Complexity classes [CFLS97, CKS81, P85, *etc.*]
  - Cost of anarchy, complexity of equilibria, *etc*. [KP99,CV02,DPS02]
- Algorithmic Mechanism Design (AMD)
  - Centralized computation [NR01]
- Distributed Algorithmic Mechanism Design (DAMD)
  - Internet-based computation [FPS01]

DAMD: Two Themes

- Incentives in Internet computation
  - Well-defined formalism
  - Real-world incentives hard to characterize
- Modeling Internet-style computation
  - Real-world examples abound
  - Formalism is lacking

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System Notation

Outcomes and *agents*:

- Φ is set of possible *outcomes.*
    - $o \in \Phi$ represents particular outcome.
- Agents have valuation functions v_i.
    - $v_i(o)$ is "happiness" with outcome o.

Societal vs. Private Goals

- System-wide performance goals:
  - Efficiency, fairness, *etc*.
  - Defined by set of outcomes $G(v) \subset \Phi$
- Private goals: Maximize own welfare
  - v_i is private to agent i.
  - Only reveal truthfully if in own interest

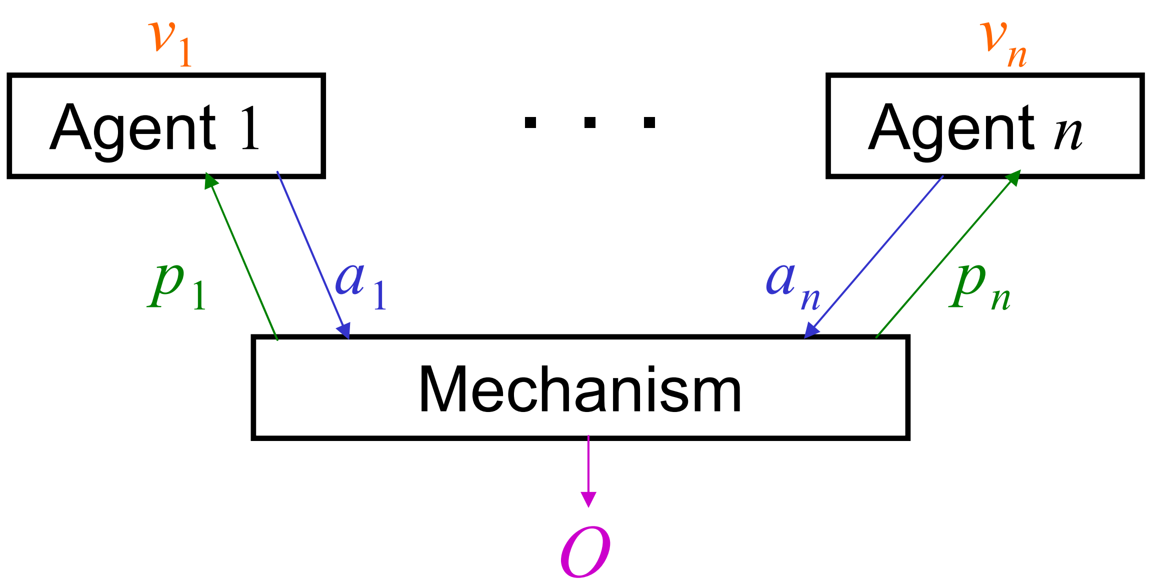
Mechanism Design

- Branch of game theory:
  - reconciles private interests with social goals
- Involves esoteric game-theoretic issues
  - will avoid them as much as possible
  - only present MD content relevant to DAMD

Mechanisms

Actions: a_i Outcome: $O(a)$ Payments: $p_i(a)$

Utilities: $u_i(a) = v_i(O(a)) + p_i(a)$



Mechanism Design

- $A_O(v)$ = {action vectors} consistent w/selfishness
  - a_i "maximizes" $u_i(a) = v_i(O(a)) + p_i(a)$.
  - "maximize" depends on information, structure, *etc.*
  - *Solution concept:* Nash, Rationalizable, ESS, *etc.*

- Mechanism-design goal: $O(A_O(v)) \subseteq G(v)$ for all v

- Central MD question: *For given solution concept, which social goals can be achieved?*

Direct Strategyproof Mechanisms

- *Direct*: Actions are declarations of v_i.
- *Strategyproof*: $u_i(v) \geq u_i(v_{-i}, x_i)$, for all x_i, v_{-i}
  - Agents have no incentive to lie.
  - $A_O(v) = \{v\}$ *"truthful revelation"*
- *Which social goals achievable with SP?*

Strategyproof Efficiency

Efficient outcome: maximizes Σv_i

VCG Mechanism:

- $O(v) = \tilde{o}(v)$ where $\tilde{o}(v) = \arg\max_o \Sigma v_i(o)$
- $p_i(v) = \sum_{j \neq i} v_j(\tilde{o}(v)) + h_i(v_{-i})$

Why are VCG Strategyproof?

- Focus only on agent i
  - v_i is truth; x_i is declared valuation
  - $p_i(x_i) = \sum_{j \neq i} v_j(\tilde{o}(x_i)) + h_i$

- $u_i(x_i) = v_i(\tilde{o}(x_i)) + p_i(x_i) = \sum_j v_j(\tilde{o}(x_i)) + h_i$

- Recall: $\tilde{o}(v_i)$ maximizes $\sum_j v_j(o)$

Group Strategyproofness

Definition:

- True: v_i Reported: x_i
- Lying set $S = \{i: v_i \neq x_i\}$

$$\exists\, i \in S\; u_i(x) > u_i(v) \;\Rightarrow\; \exists\, j \in S \quad u_j(x) < u_j(v)$$

- *If any liar gains, at least one will suffer.*

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Algorithmic Mechanism Design [NR01]

Require polynomial-time computability:

- $O(a)$ and $p_i(a)$

Centralized model of computation:

- good for auctions, *etc*.
- not suitable for distributed systems

Complexity of Distributed Computations (Static)

Quantities of Interest:

- Computation at nodes
- Communication:
  - total
  - hotspots
- Care about both messages and bits

“Good Network Complexity”

- Polynomial-time local computation
  - in total size or (better) node degree
- $O(1)$ messages per link
- Limited message size
  - F(# *agents, graph size, numerical inputs*)

Dynamics (partial)

- Internet systems often have "churn."
  - Agents come and go
  - Agents change their inputs
- "Robust" systems must tolerate churn.
  - most of system oblivious to most changes
- Example of dynamic requirement:
  - $o(n)$ changes trigger $\Omega(n)$ updates.

Protocol-Based Computation

- Use standardized protocol as substrate for computation.
  - relative rather than absolute complexity

- Advantages:
  - incorporates informal design guidelines
  - adoption does not require new protocol
  - example: BGP-based mech’s for routing

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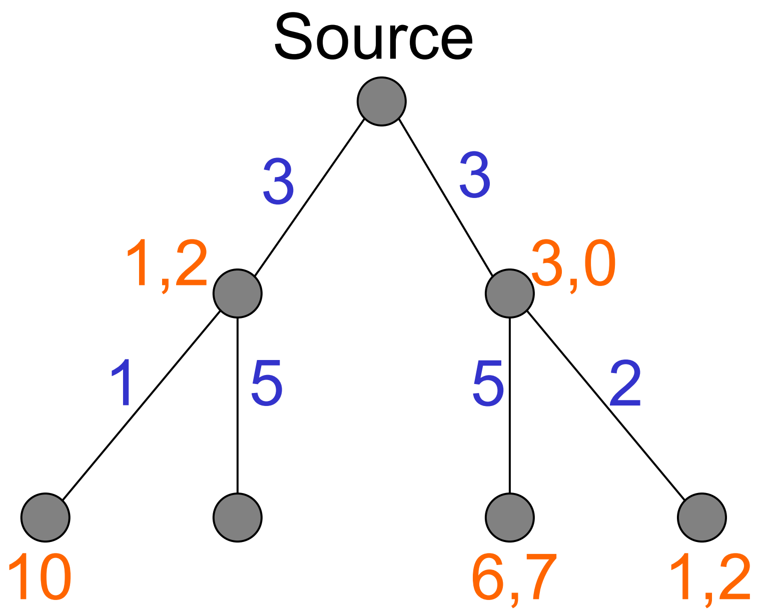
Multicast Cost Sharing (MCS)



Users' valuations: v_i

Link costs: $c(l)$

Receiver Set

Which users receive the multicast?

Cost Shares

How much does each receiver pay?

Model [FKSS03, §1.2]:

- Obedient Network
- Strategic Users

Notation

P Users (or "participants")

R Receiver set ($\sigma_i = 1$ if $i \in R$)

p_i User i's cost share (*change in sign!*)

u_i User i's utility ($u_i = \sigma_i v_i - p_i$)

W Total welfare $W(R) \triangleq V(R) - C(R)$

$$C(R) \triangleq \sum_{l \in T(R)} c(l) \qquad V(R) \triangleq \sum_{i \in R} v_i$$

“Process” Design Goals

- No Positive Transfers (NPT): $p_i \geq 0$
- Voluntary Participation (VP): $u_i \geq 0$

- Consumer Sovereignty (CS): For all trees and costs, there is a μ_{cs} s.t. $\sigma_i = 1$ if $v_i \geq \mu_{\text{cs}}$.

- Symmetry (SYM): If i,j have zero-cost path and $v_i = v_j$, then $\sigma_i = \sigma_j$ and $p_i = p_j$.

Two "Performance" Goals

- Efficiency (EFF): $R = \arg\max W$
- Budget Balance (BB): $C(R) = \sum_{i \in R} p_i$

Impossibility Results

Exact [GL79]: No strategyproof mechanism can be both efficient and budget-balanced.

Approximate [FKSS03]: No strategyproof mechanism that satisfies NPT, VP, and CS can be both γ-approximately efficient and κ-approximately budget-balanced, for any positive constants γ, κ.

Efficiency

Uniqueness [MS01]: The only strategyproof, efficient mechanism that satisfies NPT, VP, and CS is the Marginal-Cost mechanism (MC):

$$p_i = v_i - (W - W^{-i}),$$

where W is maximal total welfare, and W^{-i} is maximal total welfare without agent i.

- MC also satisfies SYM.

Budget Balance (1)

General Construction [MS01]: Any cross-monotonic cost-sharing formula results in a group-strategyproof and budget-balanced cost-sharing mechanism that satisfies NPT, VP, CS, and SYM.

- R is biggest set s. t. $p_i(R) \leq v_i$, for all $i \in R$.

Budget Balance (2)

- *Efficiency loss* [MS01]: The Shapley-value mechanism (SH) minimizes the worst-case efficiency loss.

- SH Cost Shares: $c(l)$ is shared equally by all receivers downstream of l.

Network Complexity for BB

Hardness [FKSS03]: Implementing a group-strategyproof and budget-balanced mechanism that satisfies NPT, VP, CS, and SYM requires sending $\Omega(|P|)$ bits over $\Omega(|L|)$ links in worst case.

- *Bad network complexity!*

Network Complexity of EFF

"*Easiness*" [FPS01]: MC needs only:

- One modest-sized message in each link-direction
- Two simple calculations per node

- *Good network complexity!*

Computing Cost Shares

$$p_i \equiv v_i - (W - W^{-i})$$

Case 1: No difference in tree

Welfare Difference = v_i

Cost Share = 0

Case 2: Tree differs by 1 subtree.

Welfare Difference = W^γ

(minimum welfare subtree above i)

Cost Share = $v_i - W^\gamma$

Two-Pass Algorithm for MC

Bottom-up pass:

- Compute subtree welfares W^{γ}.
- If $W^{\gamma} < 0$, prune subtree.

Top-down pass:

- Keep track of minimum welfare subtrees.
- Compare v_i to minimal W^{γ}.

Profit Maximization [FGHK02]

Mechanism:

- Treat each node as a separate "market."
- Clearing prices approx. maximize revenue.
- Find profit-maximizing subtree of markets.
- Satisfies NPT and VP but not CS or SYM.

Properties:

- Strategyproof and $O(1)$ messages per link
- Expected constant fraction of maximum profit if
  - maximum profit margin is large (> 300%), and
  - there is real competition in each market

Multiple Transmission Rates [AR02]

r = # rates h = tree height K = size of numerical input

One layer per rate ("layered paradigm"):

- MC is computable with three messages per link and $O(rhK)$ bits per link.
- For worst-case instances, average number of bits per link needed to compute MC is $\Omega(rK)$.

One multicast group per rate ("split-session paradigm"):

- Same MC algorithm has communication and computational complexity proportional to 2^r.
- For variable r, no polynomial-time algorithm can approximate total welfare closely, unless NP=ZPP.

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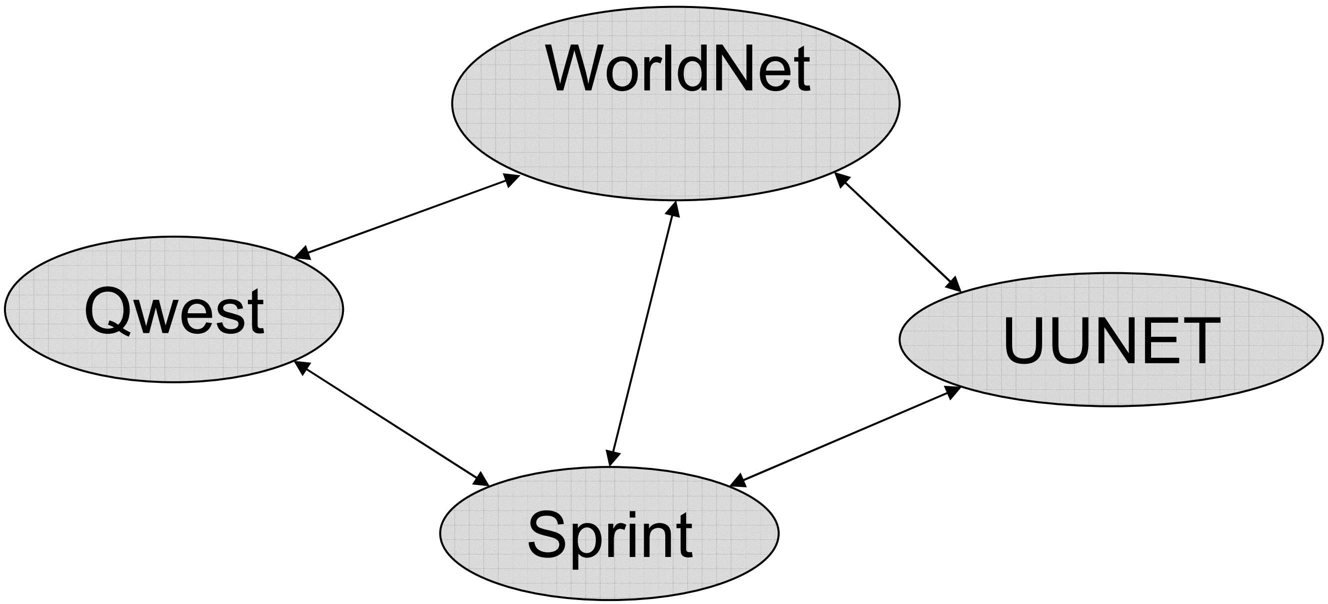
Interdomain Routing



Agents: Transit ASs

Inputs: Routing Costs or Preferences

Outputs: Routes, Payments

Lowest-Cost Routing

- Agent k's private info: per-packet cost c_k
- Mechanism-design goal: LCPs
- Centralized computation:
  - *P*-time VCG mechanism [NR01]
  - Faster *P*-time VCG mechanism [HS01]
- Distributed computation [FPSS02]:
  - BGP-based algorithm for VCG mechanism
  - All source-destination pairs

Policy-Routing

- Agents have preferences over routes:

  $$v_i : \{P_{ij}\} \to \Re^{\geq 0}$$

- Goal: routing tree maximizing $\sum_i v_i(P_{ij})$
- Arbitrary preferences [S03]:

  NP-hard to approximate w/in factor $O(n^{1/4-\varepsilon})$
- First-hop preferences [S03]:
  - *P*-time (centralized) VCG mechanism
  - No good distributed implementation (dyn.)

Supply-Chain Auctions

- Problem: concurrent auctions where activities must be coordinated across markets
  - Example: Markets for rubber, tires, trucks
- Solution [BN01]: Mechanism that propagates supply and demand curves along the chain
  - Strategyproof and achieves material balance
- Communication complexity:
  - Naïve algorithm sends $\Omega(q)$ prices per link.
  - Use binary search to find traded quantity.
    $\Rightarrow O(\log q)$ prices per link

Peer-to-Peer Networks

Distributed rating system [DGGZ03]:

- Constructs "reputation" of each peer
- Prevents lying (strategyproof)

Fair allocation of resources [NWD03]:

- Strategyproof revelation of true usage

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  - BGP-based interdomain-routing mechanisms
  - Canonically hard DAMD problems
  - Distributed implementation challenges
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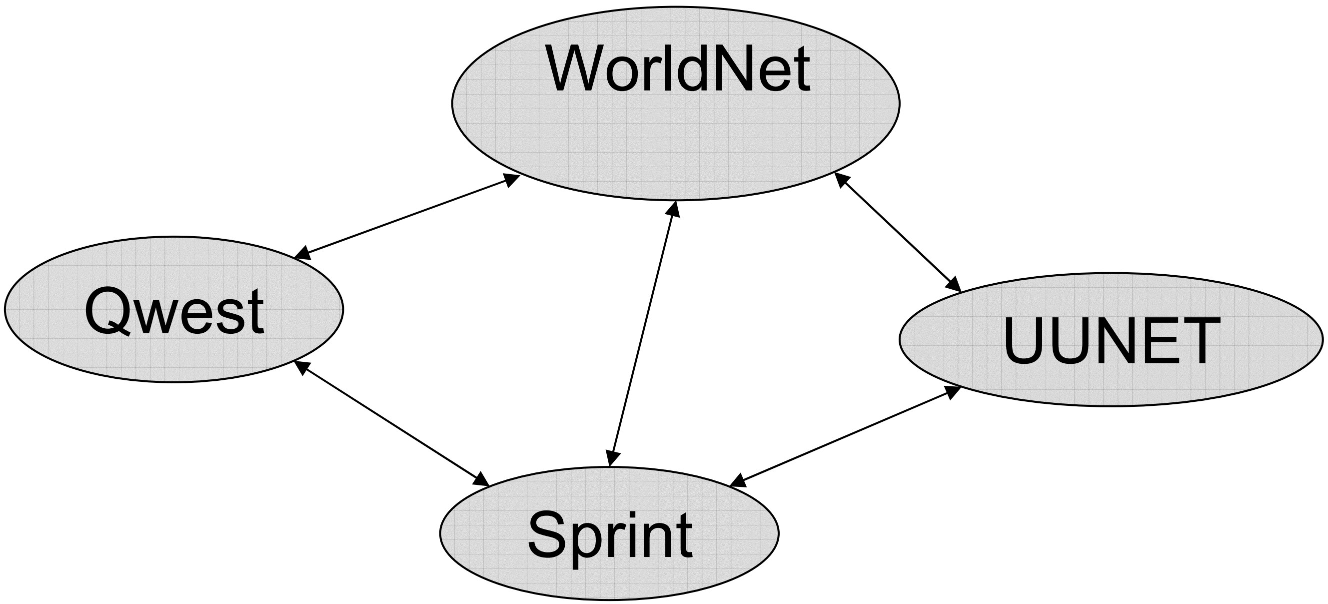
Interdomain-Routing Mechanism-Design Problem



Agents: Transit ASs

Inputs: Routing Costs or Preferences

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Lowest-Cost-Routing MD

Agents' valuations: Per-packet costs $\{c_k\}$

(Unknown) global parameter: Traffic matrix $[T_{ij}]$

Outputs: $\{route(i, j)\}$

Payments: $\{p^k\}$

Objectives:

- Lowest-cost paths (LCPs)
- Strategyproofness
- "BGP-based" distributed algorithm

A Unique VCG Mechanism

Theorem [FPSS02]:

For a biconnected network, if LCP routes are always chosen, there is a unique strategyproof mechanism that gives no payment to nodes that carry no transit traffic. The payments are of the form

$$p^k = \sum_{i,j} T_{ij}\, p_{ij}^k, \qquad \text{where}$$

$$p_{ij}^k = c_k + \text{Cost}\left(P^{-k}(c;\, i, j)\right) - \text{Cost}\left(P(c;\, i, j)\right)$$

Proof is a straightforward application of [GL79].

Features of this Mechanism

- Payments have a very simple dependence on traffic $[T_{ij}]$: Payment p^k is weighted sum of per-packet prices p^k_{ij}.
- Cost c_k is independent of i and j, but price p^k_{ij} depends on i and j.
- Price p^k_{ij} is 0 if k is not on LCP between i, j.
- Price p^k_{ij} is determined by cost of min-cost path from i to j not passing through k (min-cost "k-avoiding" path).

BGP-Based Computational Model (1)

- Follow abstract BGP model of [GW99]:
  Network is a graph with nodes corresponding to ASs and bidirectional links; intradomain-routing issues are ignored.

- Each AS has a routing table with LCPs to all other nodes:

Dest.	LCP				LCP cost
AS1	AS3	AS5	AS1		3
AS2	AS7	AS2			2

Entire paths are stored, not just next hop.

Computational Model (2)

- An AS "advertises" its routes to its neighbors in the AS graph, whenever its routing table changes.

- The computation of a single node is an infinite sequence of stages:

- Complexity measures:
  - Number of stages required for convergence
  - Total communication

★ Surprisingly *scalable* in practice.

Computing the VCG Mechanism

- Need to compute *routes* and *prices*.
- Routes: Use Bellman-Ford algorithm to compute LCPs and their costs.
- Prices:

$$p_{ij}^{k} = c_k + \boxed{\text{Cost}\left(P^{-k}(c;\, i, j)\right)} - \text{Cost}\left(P(c;\, i, j)\right)$$

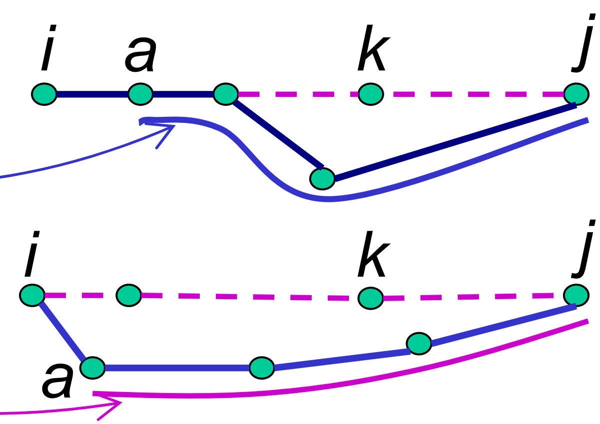
$\Rightarrow$ Need algorithm to compute cost of min-cost k-avoiding path.

Structure of k-avoiding Paths

- BGP uses communication between neighbors only
  $\Rightarrow$ we need to use "local" structure of $P^{-k}(c;\, i,j)$.
- Tail of $P^{-k}(c;\, i,j)$ is either of the form

(1) $P^{-k}(c;\, a,j)$

or (2) $P(c;\, a,j)$

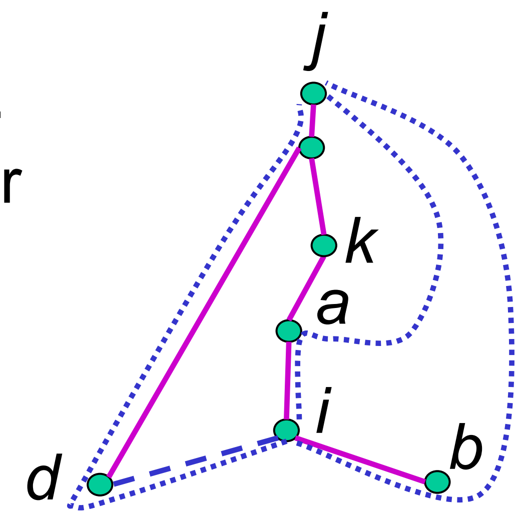


- Conversely, for each neighbor a, either $P^{-k}(c;\, a,j)$ or $P(c;\, a,j)$ gives a candidate for $P^{-k}(c;\, i,j)$.

Computing the Prices

- Classifying neighbors:
  - Set of LCPs to j forms a tree.
  - Each of i's neighbors is either
    - (*a*) parent
    - (*b*) child
    - (*d*) unrelated

    in tree of LCPs to j.



- Each case gives a candidate value for p_{ij}^{k} based on neighbor's LCP cost or price, *e.g.*,

  (b) $p_{ij}^{k} \leq p_{bj}^{k} + c_b + c_i$

- p_{ij}^{k} is the minimum of these candidate values

  $\Rightarrow$ compute it locally with dynamic programming.

A "BGP-Based" Algorithm

Dest.	cost	LCP and path prices				LCP cost
AS1		AS3	AS5	AS1		$c(i,1)$
	c_1	p_{i1}^{3}	p_{i1}^{5}			

1. LCPs are computed and advertised to neighbors.
2. Initially, all prices are set to ∞.
3. In the following stages, each node repeats:
   - Receive LCP costs and path prices from neighbors.
   - Recompute candidate prices; select lowest price.
   - Advertise updated prices to neighbors.

Final state: Node i has accurate p_{ij}^{k} values.

Performance of Algorithm

$$d = max_{i,j} \,||\, P(c;\, i, j) \,||$$

$$d' = max_{i,j,k} \,||\, P^{-k}(c;\, i, j) \,||$$

Theorem [FPSS02]:
This algorithm computes the VCG prices correctly, uses routing tables of size $O(nd)$ (a constant factor increase over BGP), and converges in at most $(d + d')$ stages (worst-case additive penalty of d' stages over the BGP convergence time).

Dealing with Strategic Computation

- Restoring strategyproofness: Cost c_k must be the only path information that AS k can manipulate.

- Possible because all other information reported by AS k is known to at least one other party, hence not "private" information of AS k.

- Solution [MSTT]: All information is signed by originating party.

  cost c_i: signed by AS i.

  existence of link ij: signed by AS i and AS j.

  AS k's message has to include all relevant signatures.

- AS k cannot benefit by suppressing real paths to k.

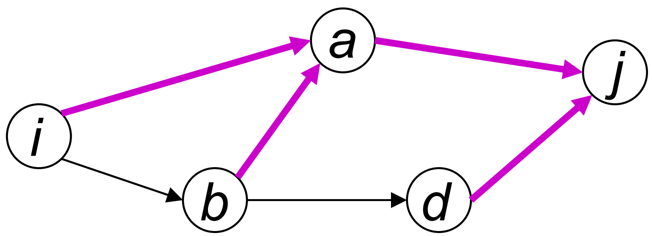
Modified BGP-Update Messages

Update from AS k to AS j for route to AS1:

Dest.	cost	LCP and path prices			LCP cost
AS1		AS3	AS5	AS1	$c(k,1)$
		p_{k1}^{3}	p_{k1}^{5}		
	c_k	c_3	c_5		
	$s_k(c_k)$	$s_3(c_3)$	$s_5(c_5)$		
	$s_k(l_{kj})$	$s_3(l_{3k})$	$s_5(l_{53})$	$s_1(l_{15})$	

General Policy-Routing Problem Statement

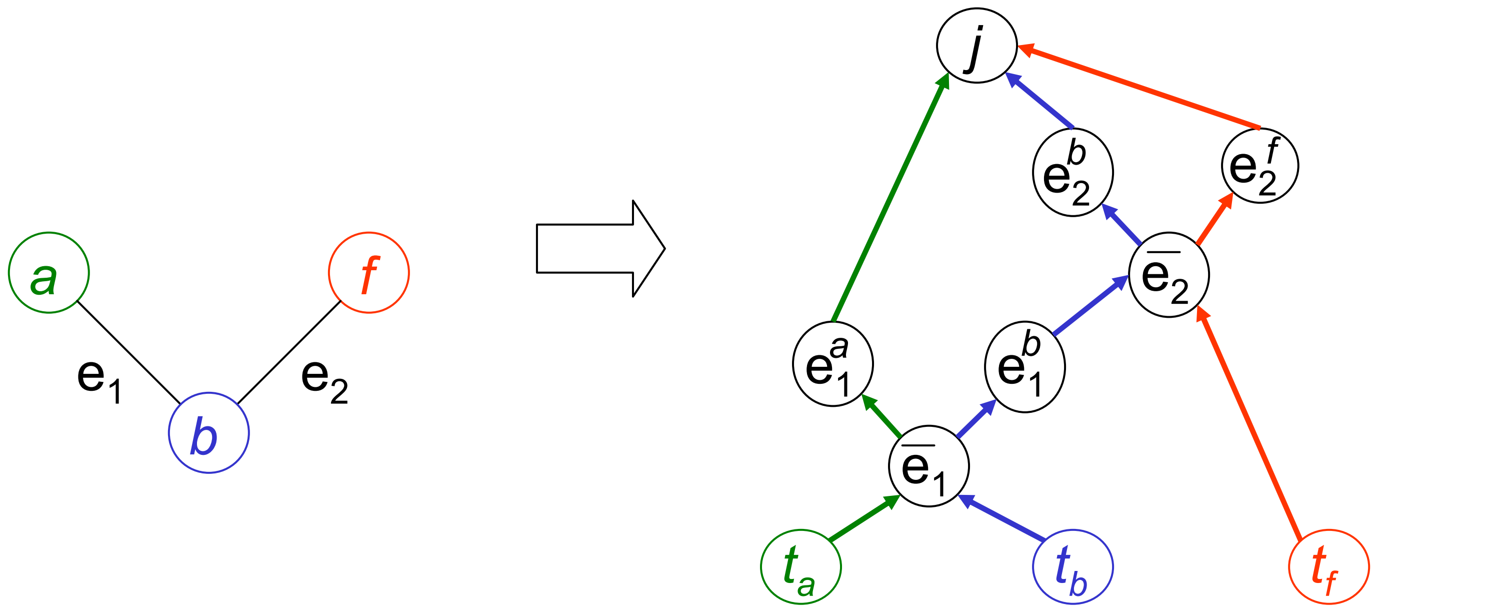
- Consider each destination j separately.
- Each AS i assigns a value $v_i(P_{ij})$ to each potential route P_{ij}.



- Mechanism-design goals:
  - Maximize $W = \sum_i v_i(P_{ij})$.
  - For each destination j, $\{P_{ij}\}$ forms a tree.
  - Strategyproofness
  - BGP-based distributed algorithm

NP-Hardness with Arbitrary Valuations

- Approximability-preserving reduction from Independent-set problem:



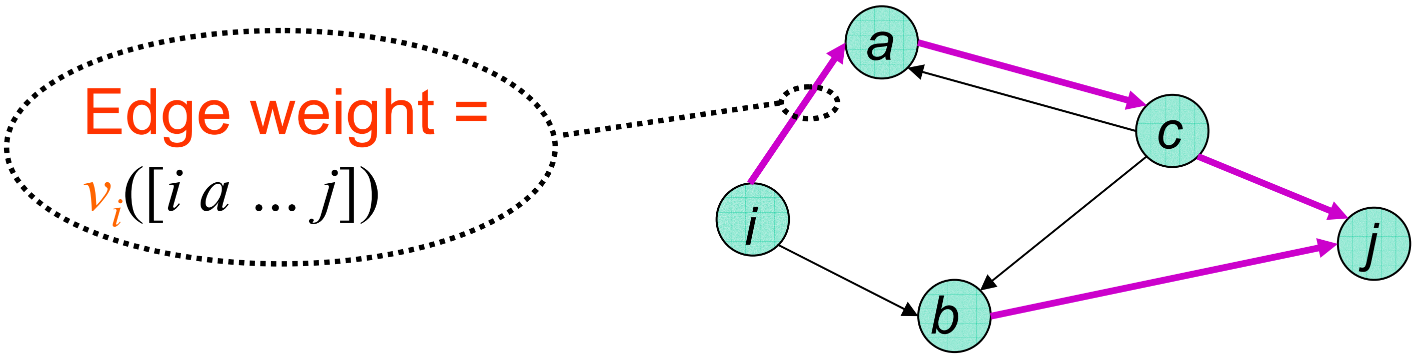
Paths from terminals t_a, t_b, t_f have valuation 1, all other paths 0.

- NP-hard to compute maximum W exactly.
- NP-hard to compute $O(n^{1/4 - \varepsilon})$ approximation to maximum W.

First-Hop Preferences

- $v_i(P_{ij})$ depends only on first-hop AS a.
- Captures preferences due to customer/provider/peer agreements.

For each destination j , optimal routing tree is a Maximum-weight Directed Spanning Tree (MDST):



Strategyproof Mechanism

Let

T^* = Maximum weight directed spanning tree (MDST) in G

T^{-i} = MDST in $G - \{i\}$

- For biconnected networks, there is a unique strategyproof mechanism that always picks a welfare-maximizing routing tree and never pays non-transit nodes. The payments required for this mechanism are

$$p^i = W(T^*) - v_i(T^*) - W(T^{-i})$$

- Routes and payments can be computed in polynomial time (in a centralized computational model).

Proving Hardness for "BGP-Based" Routing Mechanisms [S03]

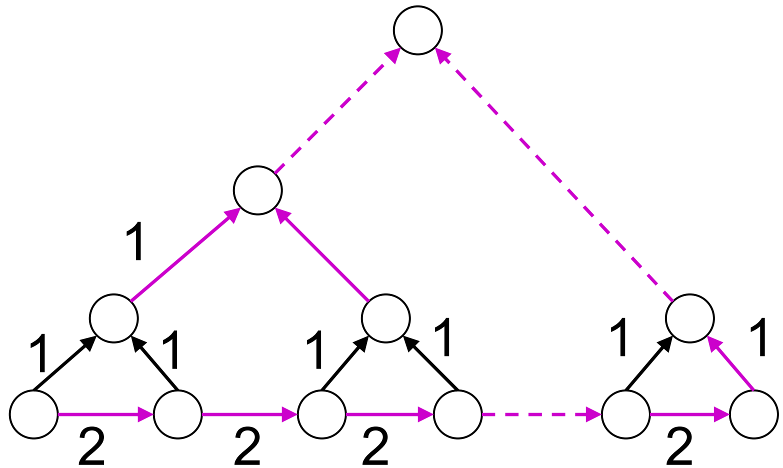
- Need to formalize requirements for "BGP compatibility."
- Hardness results need only hold for:
  - "Internet-like" graphs
    - $O(1)$ average degree
    - $O(\log n)$ diameter and $O(\log n)$ diameter′
  - An open set of numerical inputs in a small range

Reasonable Routing-Table Size and Convergence Time

- Each AS uses $O(l)$ space for a route of length l.
- Length of longest routes chosen (and convergence time) should be proportional to network diameter or diameter′.
- See related work on formal models of "path-vector" routing protocols [GJR03].

Long Paths Chosen by MDST

- Example:



- Don't even know how to compute MDST prices in time proportional to length of longest route chosen.

Reasonably Stable Routing Tables

- Most changes should not affect most routes.

- More formally, there are $o(n)$ nodes that can trigger $\Omega(n)$ update messages when they fail or change valuations.

MDST Does Not Satisfy the Stability Requirement

Proof outline:

(i) Construct a network and valuations such that, for $\Omega(n)$ nodes i, T^{-i} is disjoint from the MDST T^*.

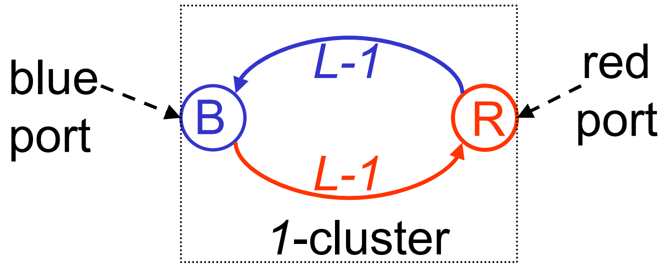
(ii) A change in the valuation of any node a may change

$$p_i = W(T^*) - v_i(T^*) - W(T^{-i}).$$

(iii) Node i (or whichever node stores p_i) must receive an update when this change happens.
$\Rightarrow$ $\Omega(n)$ nodes can each trigger $\Omega(n)$ update messages.

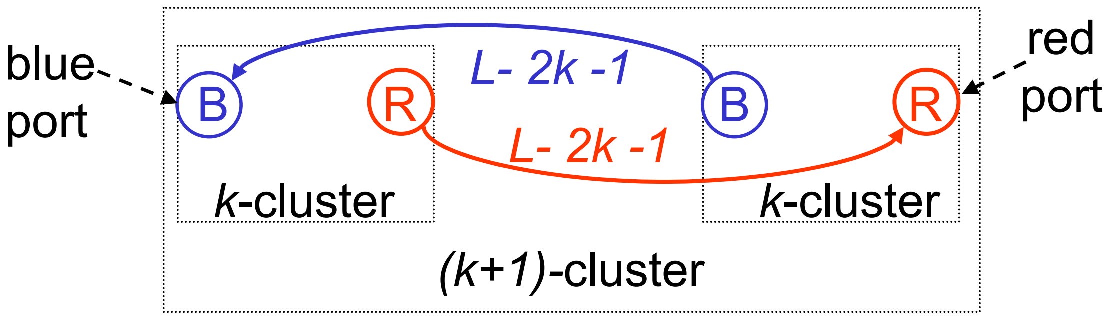
Network Construction (1)

(a) Construct *1-cluster* with two nodes:



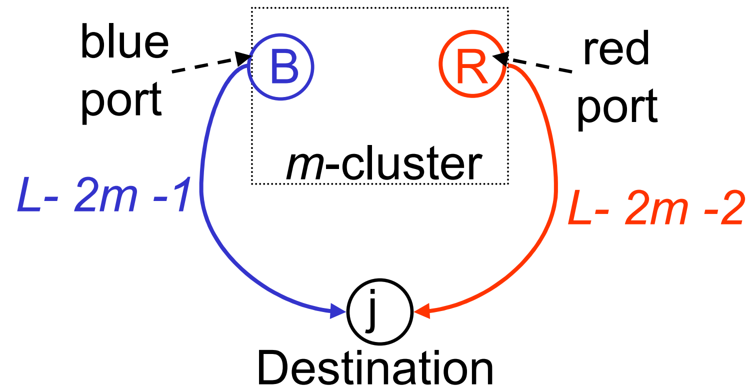
$L \approx 2 \log n + 4$

(b) Recursively construct *(k+1)*-clusters:

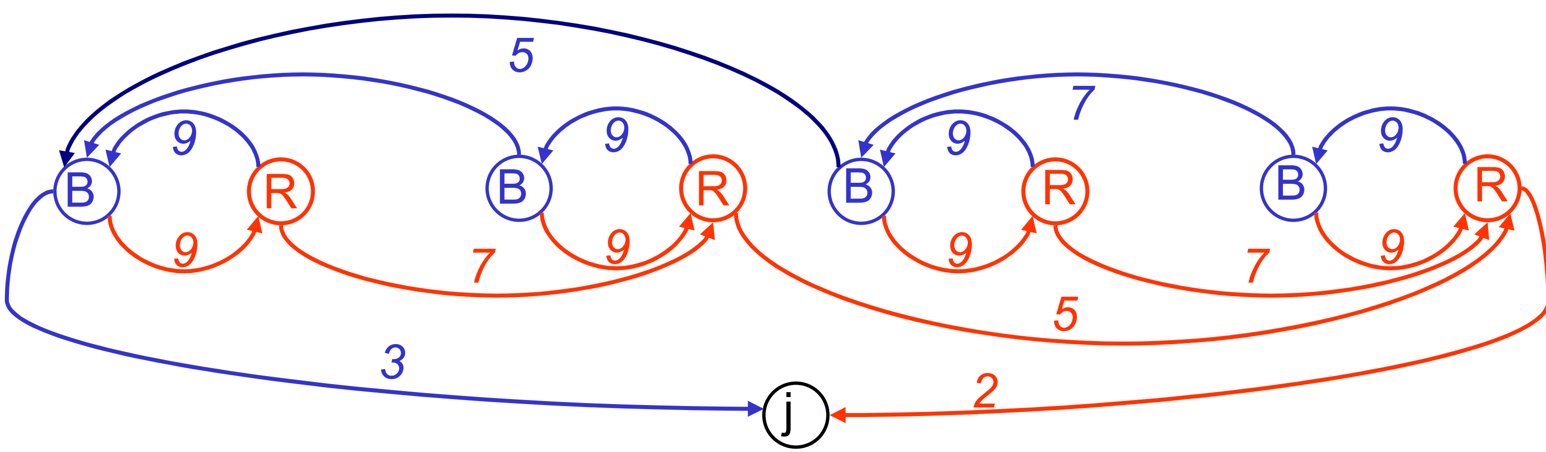


Network Construction (2)

(c) Top level: *m*-cluster with $n = 2^m + 1$ nodes.



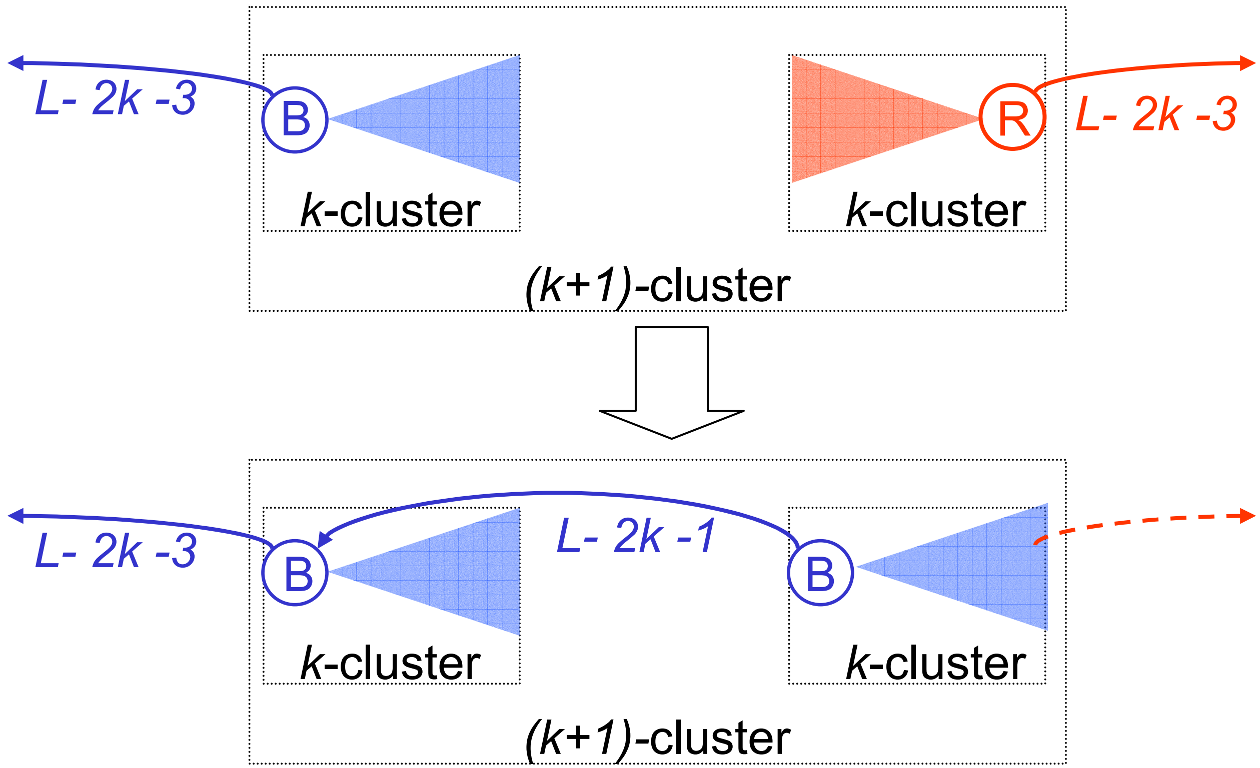
Final network (*m* = *3*):

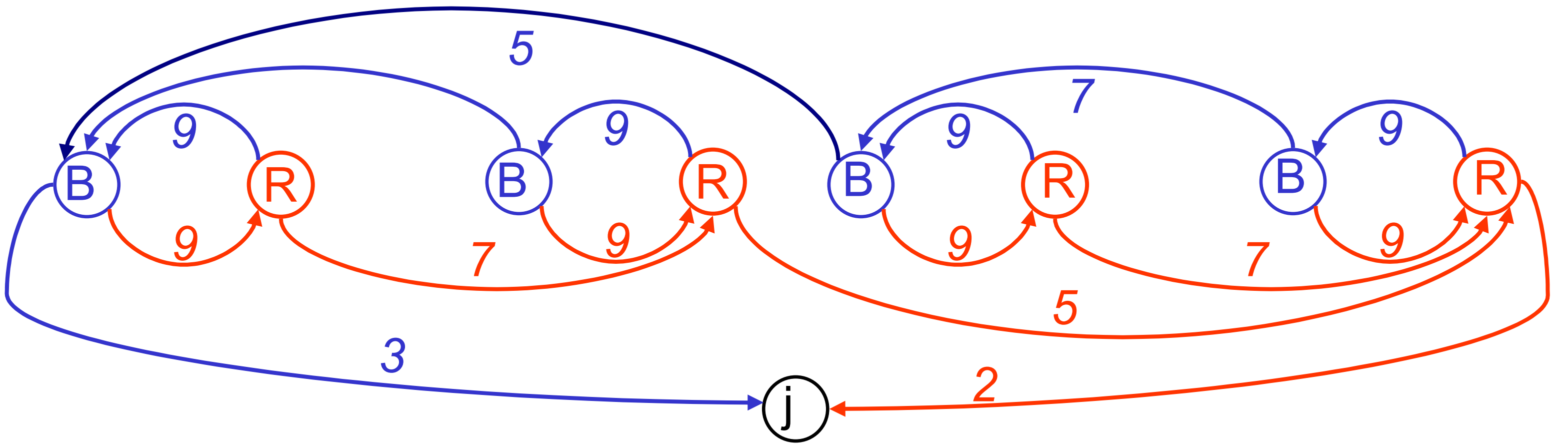


Optimal Spanning Trees

Lemma: *W*(*blue tree*) = *W*(*red tree*) + 1 ≥ *W*(*any other sp.tree*) + 2

Proof: If a directed spanning tree has red and blue edges, we can increase its weight by at least 2:





- MDST T^* is the blue spanning tree.
- For any blue node B, T^{-B} is the red spanning tree on $N - \{B\}$.
- A small change in any edge, red or blue, changes

$$p^B \quad = \quad W(T^*) - v_B(T^*) - W(T^{-B})$$

$\Rightarrow$ Any change triggers update messages to all blue nodes!

Open Questions

- BGP-compatible special case of first-hop-preferences routing
- Fully fleshed-out BGP-based computational model
  - Incremental computation
  - “Smooth” convergence?
- New DA principle: Use an Internet protocol as a “computational substrate.”

Outline

- Motivation and Background
- Example: Multicast Cost Sharing
- Overview of Known Results
- Three Research Directions
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- Open Questions

“Hard to Solve on the Internet”

Intuitively, this means

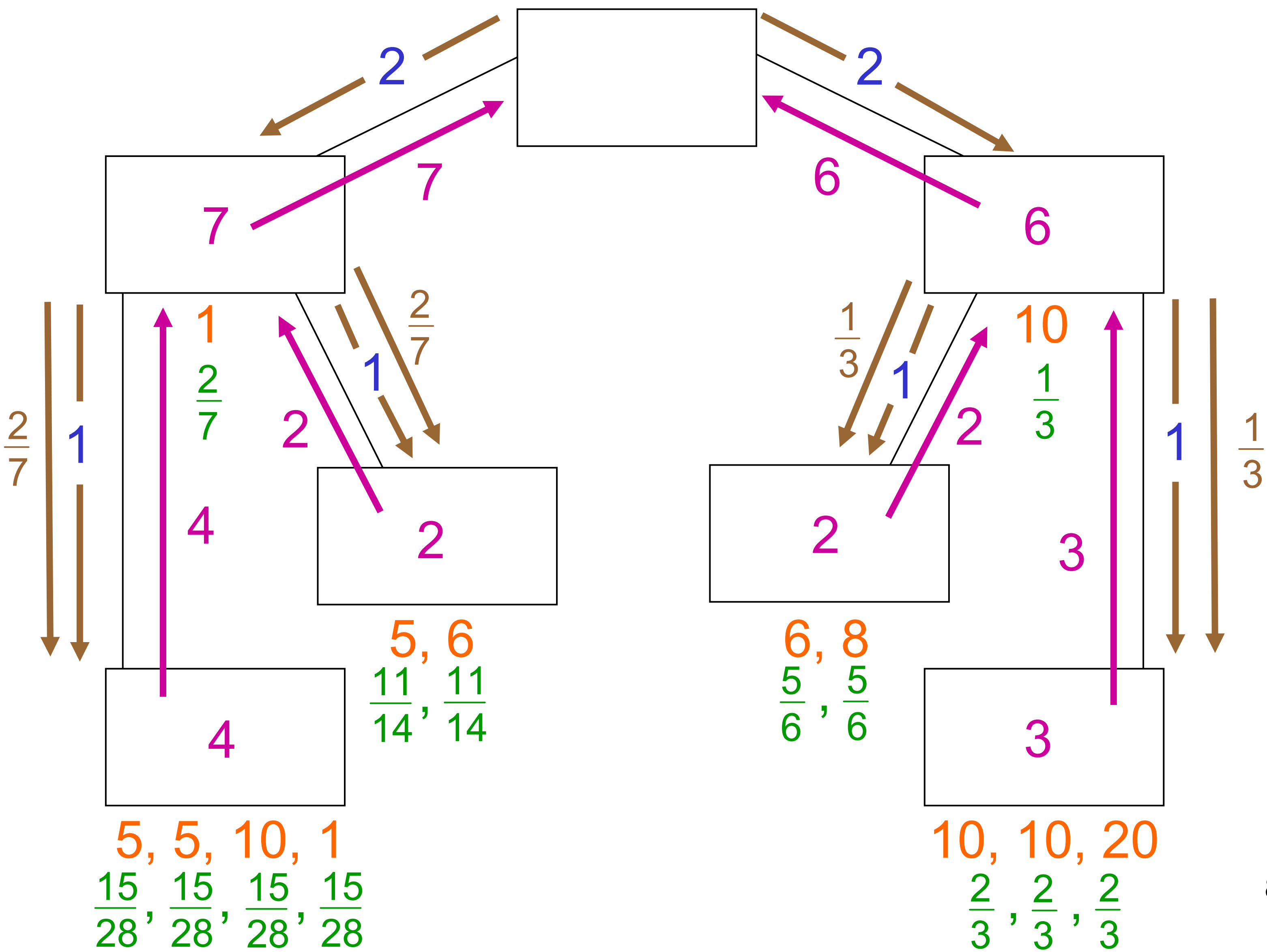
- Cannot simultaneously achieve
  - Robust scalability
  - Incentive compatibility
- Can achieve either requirement separately

Recall that BB multicast cost sharing is hard.

Scalability $\triangleq$ low (absolute) network complexity

Incentive compatibility $\triangleq$ GSP’ness

GSP'ness Without Scalability



Iterative SH Algorithm

- Start with $R = P$.
- Calculate cost shares as above.
- Eliminate from R all i s.t. current $p_i > v_i$.
- Repeat until $R \neq \emptyset$ or no i eliminated.

Worst case: $|P|$ iterations.

Lower bound in [FKSS03] shows that bad network complexity is unavoidable.

Scalability Without GSP'ness

Bottom-up pass: Compute

$$C = \sum_{l \in L} c(l) \quad \text{and} \quad V = \sum_{i \in P} v_i$$

Top-down pass:

If $C > V$, $\sigma_i = 0$ for all i

If $C \leq V$, $\sigma_i = 1$ for all i

and $p_i = (v_i \cdot C) / V$

Open Question

- More canonically hard problems?
- Open for *centralized* AMD as well
- Complexity theory of Internet computation
  - Formal models
  - Complexity classes
  - Reductions

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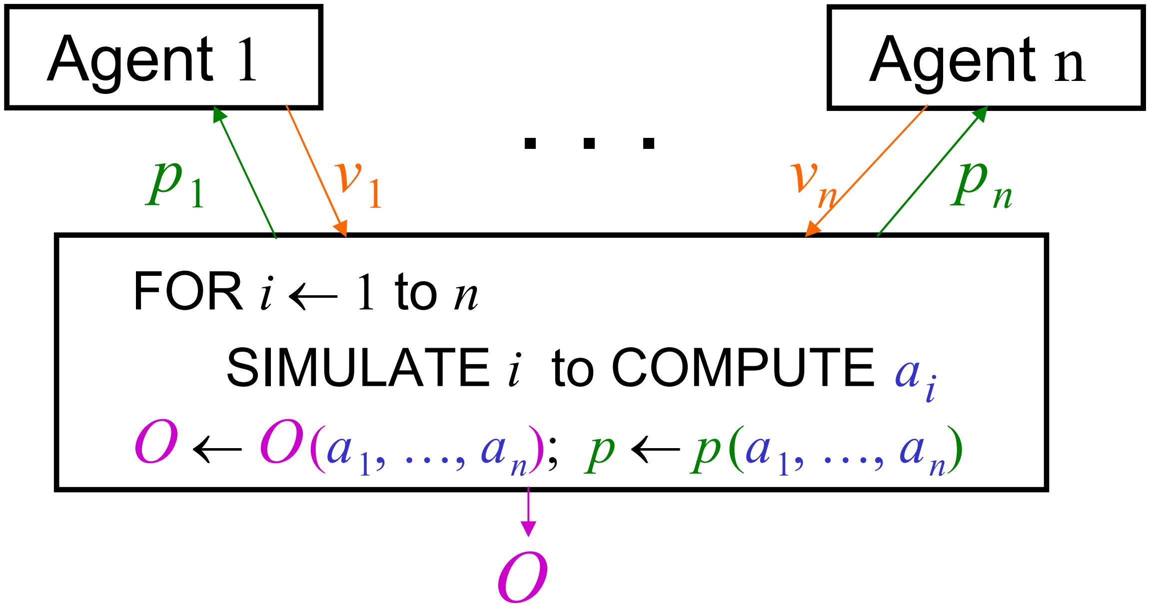
Revelation Principle

If there is a DS mechanism (O, p) that implements a design goal, then there is one that does so truthfully.



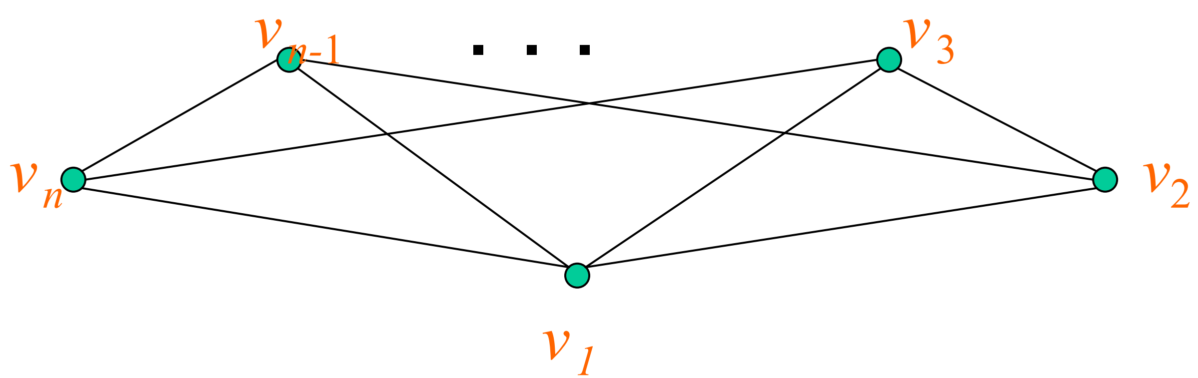
Note: Loss of privacy
Shift of computational load
Assumes centralized, obedient mechanism

Is Truthtelling Really "Dominant"?

Consider Lowest-Cost Routing:

- Mechanism is strategyproof, in the technical sense: Lying about its cost cannot improve an AS's welfare *in this particular game*.
- But truthtelling reveals to competitors information about an AS's internal network. This may be a disadvantage *in the long run.*
- Note that the goal of the mechanism is not acquisition of private inputs *per se* but rather evaluation of a function of those inputs.

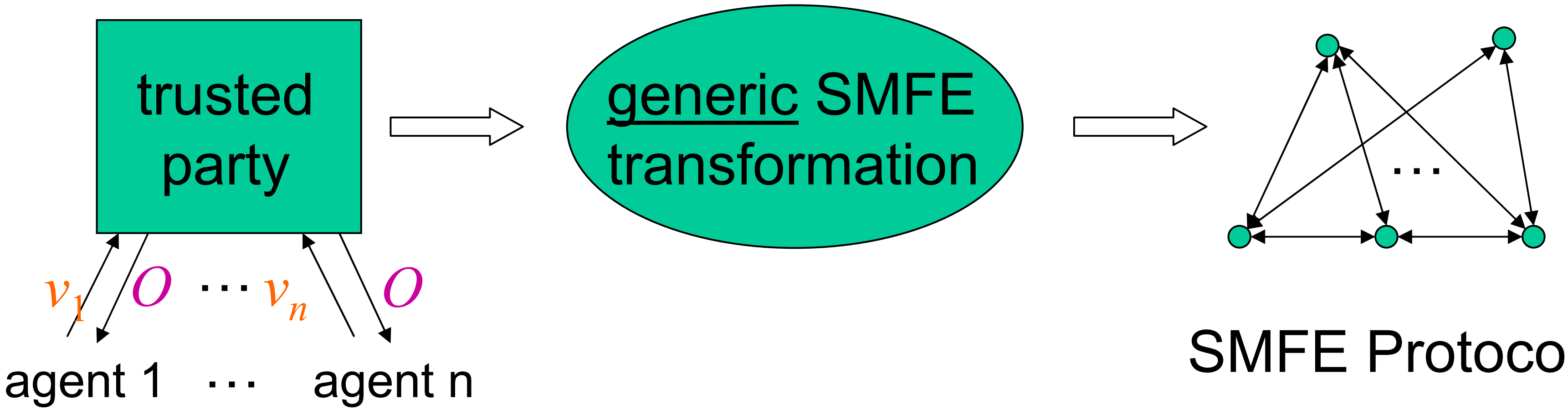
Secure, Multiparty Function Evaluation



$$O = O\,(v_1, \ldots, v_n)$$

- Each i learns O.
- No i can learn anything about v_j (except what he can infer from v_i and O).
- Extensive SMFE theory; see, *e.g.*, [C00, G02].

Constructive, "Compiler"-Style Results



Natural approach:

centralized mechanism ≈ trusted party

DAM ≈ SMFE protocol

Must be careful about strategic models and solution concepts.

Combining MD and SMFE

Example: Transform a centralized, strategyproof mechanism using the "secure" (against an active adversary) protocol construction in [BGW88] (with $t = 1$). Result is:

- An *input game*, with a dominant-strategy equilibrium in which every agent "shares" his true valuation.
- A *computational game*, with a Nash equilibrium in which every agent follows the protocol.
- Agent privacy!

Need specific properties of [BGW88] construction (*e.g.*, initial input commitment) as well as general definition of security.

Open Questions

- Complete understanding of what follows from known SMFE constructions
- Privacy-preserving DAMs that have good network complexity
- New solution concepts designed for Internet computation
- New kinds of mechanisms and protocols with highly transient sets of agents

Outline

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- Distributed implementation challenges
- Other research directions

More Problem Domains

- Caching
- Distributed Task Allocation
- Overlay Networks
- ★ Ad-hoc and/or Mobile Networks
- …

Ad-Hoc and/or Mobile Networks

- Nodes make same incentive-sensitive decisions as in traditional networks, *e.g.*:
  - Should I connect to the network?
  - Should I transit traffic?
  - Should I obey the protocol?
- These decisions are made more often and under faster-changing conditions than they are in traditional networks.
- Resources (*e.g.*, bandwidth and power) are scarcer than in traditional networks. Hence:
  - Global optimization is more important.
  - Selfish behavior by individual nodes is potentially more rewarding.

Approximation in DAMD

- AMD approximation is subtle. One can easily destroy strategyproofness.
- "Feasibly dominant strategies" [NR00]
- "Strategically faithful" approximation [AFK+03]
- "Tolerable manipulability" [AFK+03]
- "Approximate strategyproofness" [APTT03, GH03, KPS03, S01]

Indirect Mechanisms

Explore tradeoffs among

- agent computation
- mechanism computation
- communication
- privacy
- approximation factors

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