Routing Money, Not Packets

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Conversation between a prominent Economist and Dave Clark (Foundational Architect of the Internet)

- Economist: “The Internet is about routing money. Routing packets is a side-effect.”
- Economist: “You really screwed up the money-routing protocols”.
- Dave: “We did not design any money-routing protocols”.
- Economist: “That’s what I said”.

Rest of the talk

- Background
- Cooperative Games and Shapley Values
- Application of Shapley Values to Peering
- Instability of settlement free peering
- Zero Rating
- (Re)Defining Net Neutrality

ISP Settlements and Shapley Values

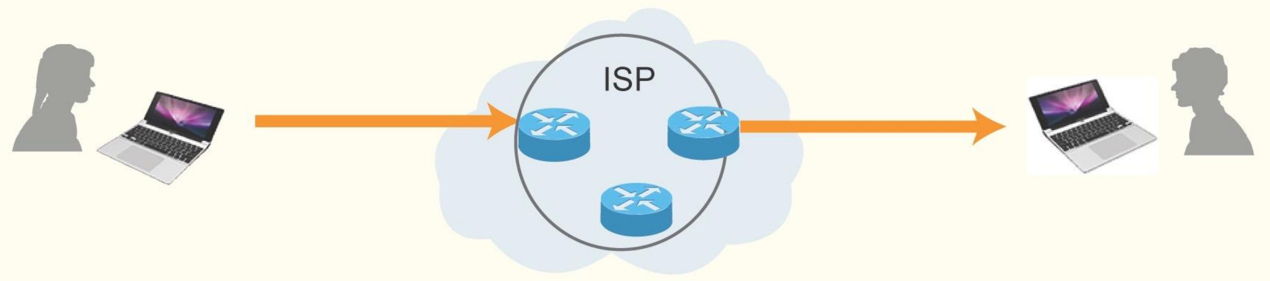
The P2P Battlefield: Engineering and Economics

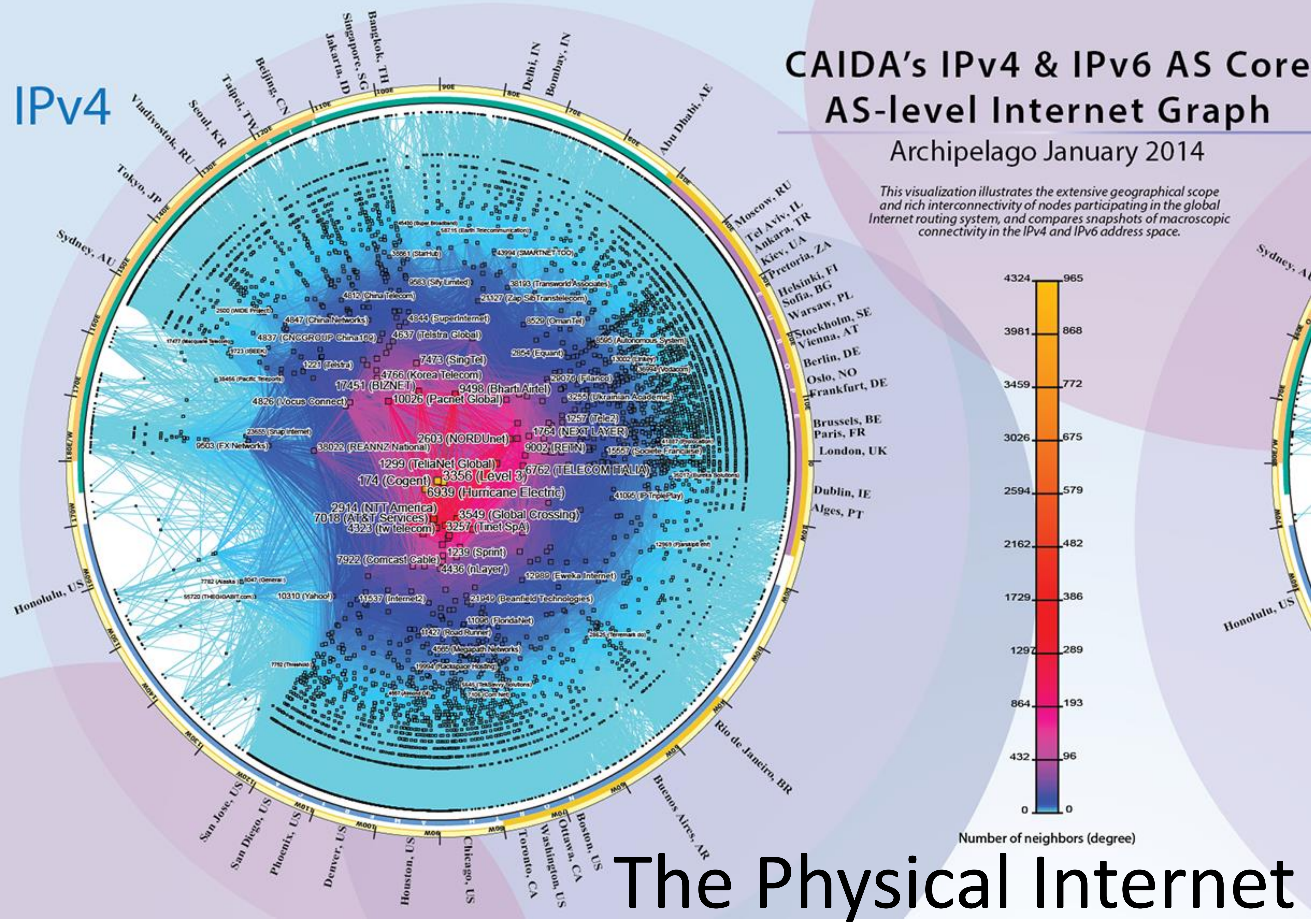
- Proposed engineering approaches:
  - ISPs: Drop P2P packets based on port number
  - Users: Dynamic port selection
  - ISPs: Deep packet inspection
  - Users: Disguise by encryption
  - ISPs: Behavioral analysis
- Comcast started throttling BitTorrent traffic

It became evident to us the problem was rooted in *Economics*, not Engineering

What were the Economists saying?

Two-sided market

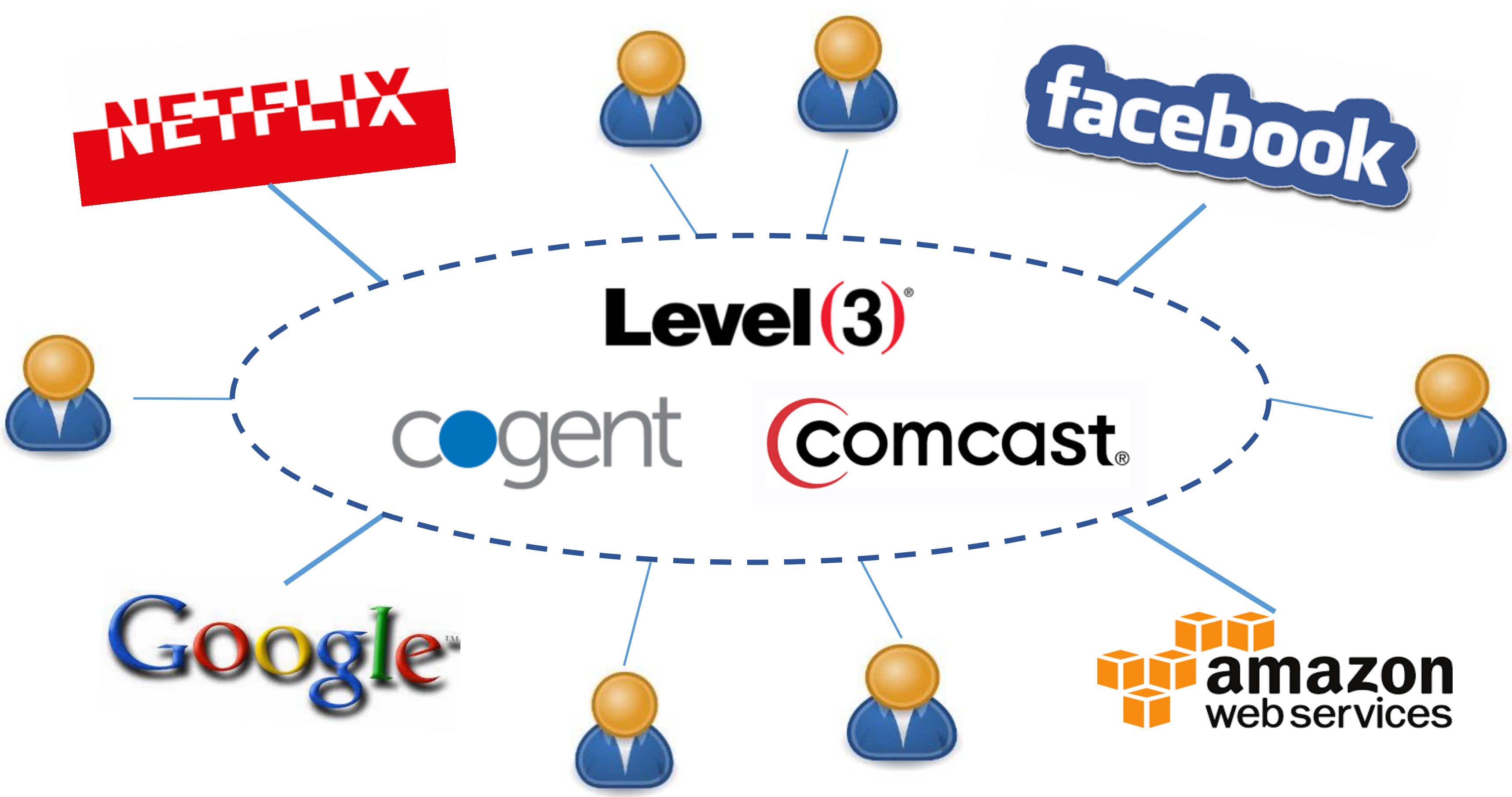




The Physical Internet

http://www.caida.org/research/topology/as_core_network/pics/2014/ascore-2014-jan-ipv4v6-poster-2000x1294.png

The Conceptual Internet Platform



Net Neutrality Debate

- Folk definition of net neutrality
  - “All data (packets) should be treated equally”
  - (Didn’t make sense to networking people)

- Failure to “route the money” makes it difficult to price packets based on their values
  - Leads to economic problems like peering disputes

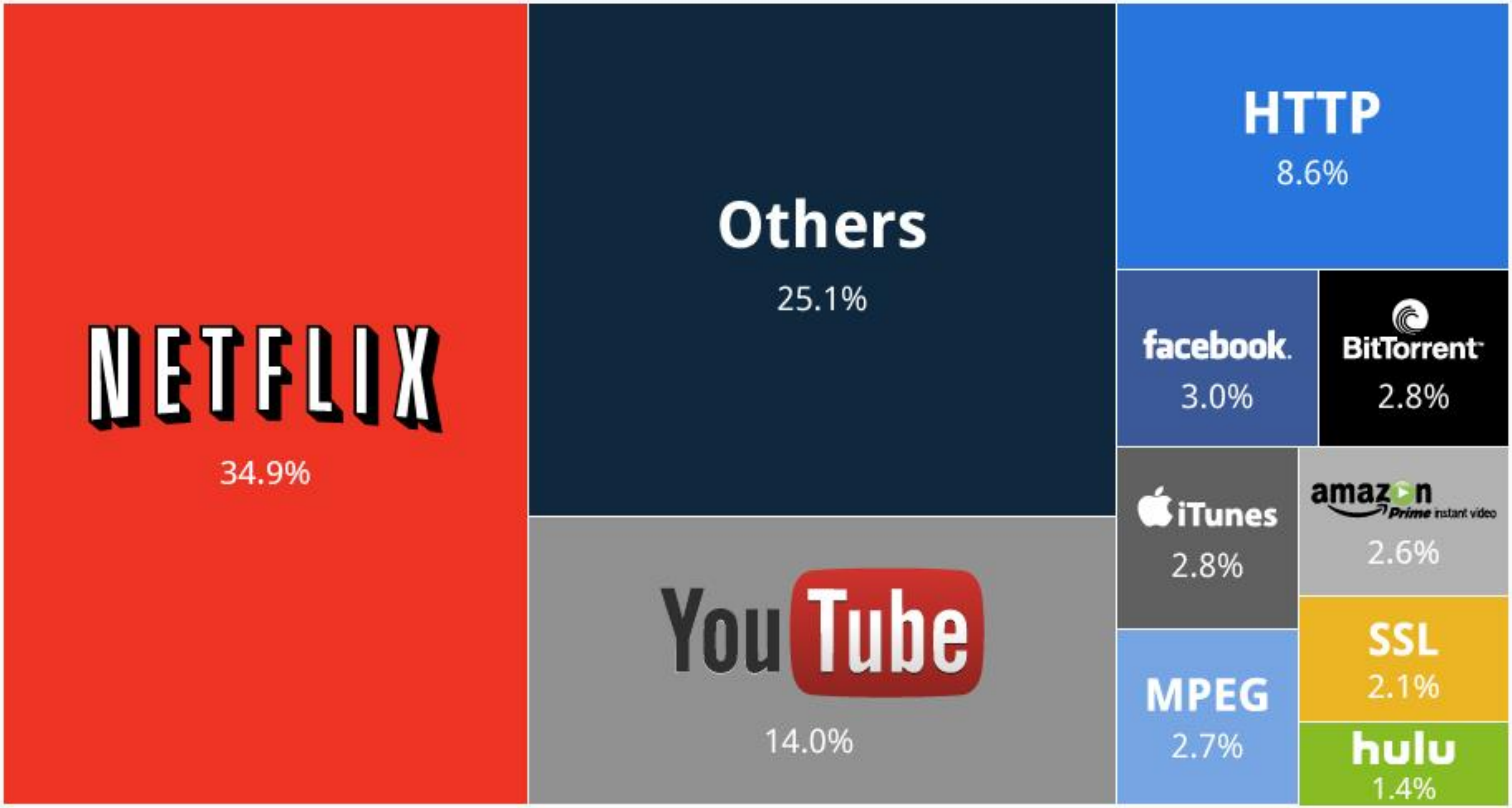
Peering Disputes Among ISPs

S.No.	Conflicting Companies	Month/Year	Reason
1.	Telecom Italia - Other ISPs	July'13	Telecom Italia was reducing the number of neutral access points
2.	Cogent - Verizon	June'13	Verizon neglected upgrading the peering connection
3.	FT Orange - Cogent + Google	Jan'13	FT-Orange restricted bandwidth for online video service Youtube
4.	Cogent - China Telecom	Mar'12	Parties de-peered for unknown reasons
5.	Cogent - France Telecom	Aug'11	France Telecom didn't allow Cogent to connect with its Customers
6.	Cogent - ESNet	June'11	ESNet was below the Cogent's minimum traffic volume threshold
7.	Level3 - Comcast	2010	Comcast started charging new fee to deliver Level3 traffic
8.	Cogent - Hurricane Electric	Oct'09	Both are IPv6 Tier 1 backbone, cogent de-peered HE
9.	Chunghwa Telecom - TFN	Apr'09	Reason not known
10.	Sprint - Cogent	Sept'08	Traffic Exchange Criteria not met
11.	Telia - Cogent	Mar'08	Imbalanced Traffic Ratios
12.	Cogent - Limelight	Sept'07	Cogent de-peered Limelight for unknown reasons
13.	Cogent - Level3	Oct-05	Link Terminated due to imbalanced Traffic Ratio
14.	AOL - MSN	Sept'03	Reasons unknown, but AOL users were not able to access MSN
15.	Cogent - AOL	Dec'02	Imbalanced Traffic Ratio
16.	C&W - PSINet	2001	C&W dropped the peering agreement
17.	BBN/Genuity/GTE - Exodus	Before 2001	Battle over imbalanced traffic flows
18.	BBN/GTE - MCI/Worldcom	Around '99	Nature of peering agreement was not clarified
19.	UUNet Whole Earth Networks Inc	May'97	UUNet demanded for paid peering
20.	UUNet- Others	May'97	UUNet notified its peers that they would terminate their peering
21.	AGIS - Others	Before '97	AGIS announced its new peering policy at the NANOG meeting
22.	Digex Inc - AGIS	Oct'96	Reasons not known
23.	Sprint - Other ISPs	Before '96	Sprint refused to upgrade its connection at the CIX router
24.	BBN - Other ISPs	Around '95	BBN terminated its connection at CIX router
25.	BBN - ANS	Around '95	BBN broke the agreement
26.	DANTE - EUNet	Oct'94	DANTE asked EUnet to increase their connection rate

S. Bafna et al.,"Anatomy of the Internet Peering Disputes", 2014

Netflix and YouTube Are America's Biggest Traffic Hogs

Percentage of peak period downstream traffic in North America, by application*



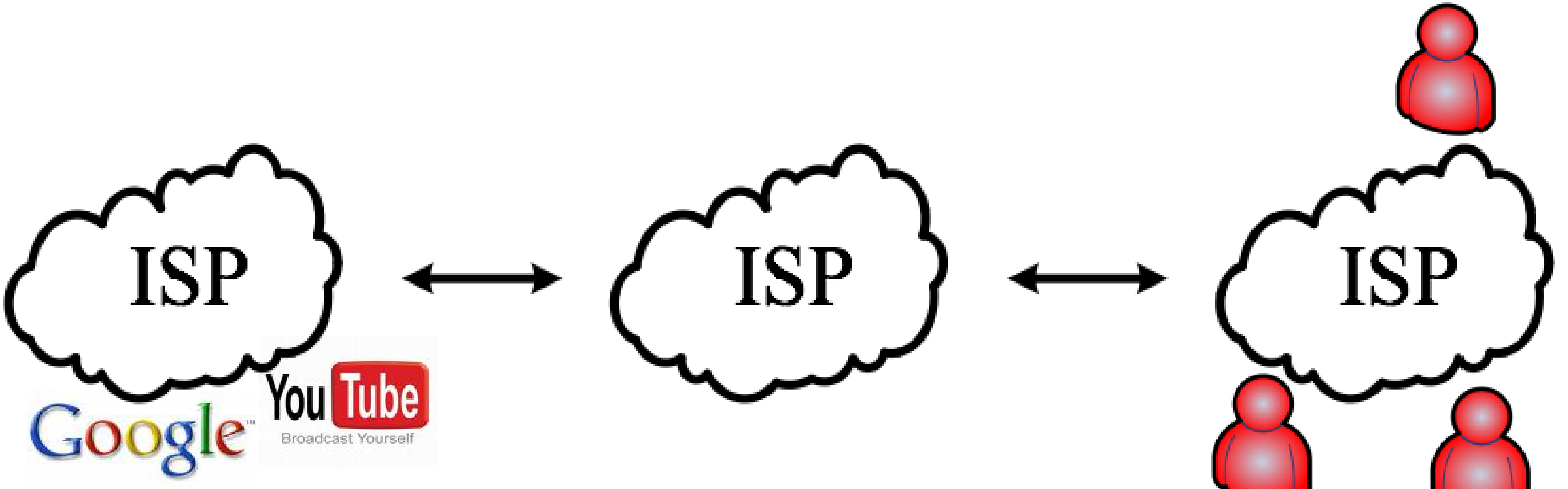
September 2014, fixed access only

Source: Sandvine

Building blocks of the Internet: ISPs

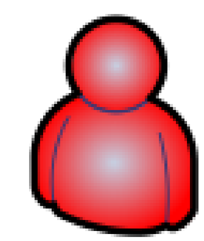
- The Internet is operated by thousands of interconnected Internet Service Providers (ISPs).

- An ISP is an autonomous business entity.
  - Provide Internet services.
  - Common objective: to make profit.

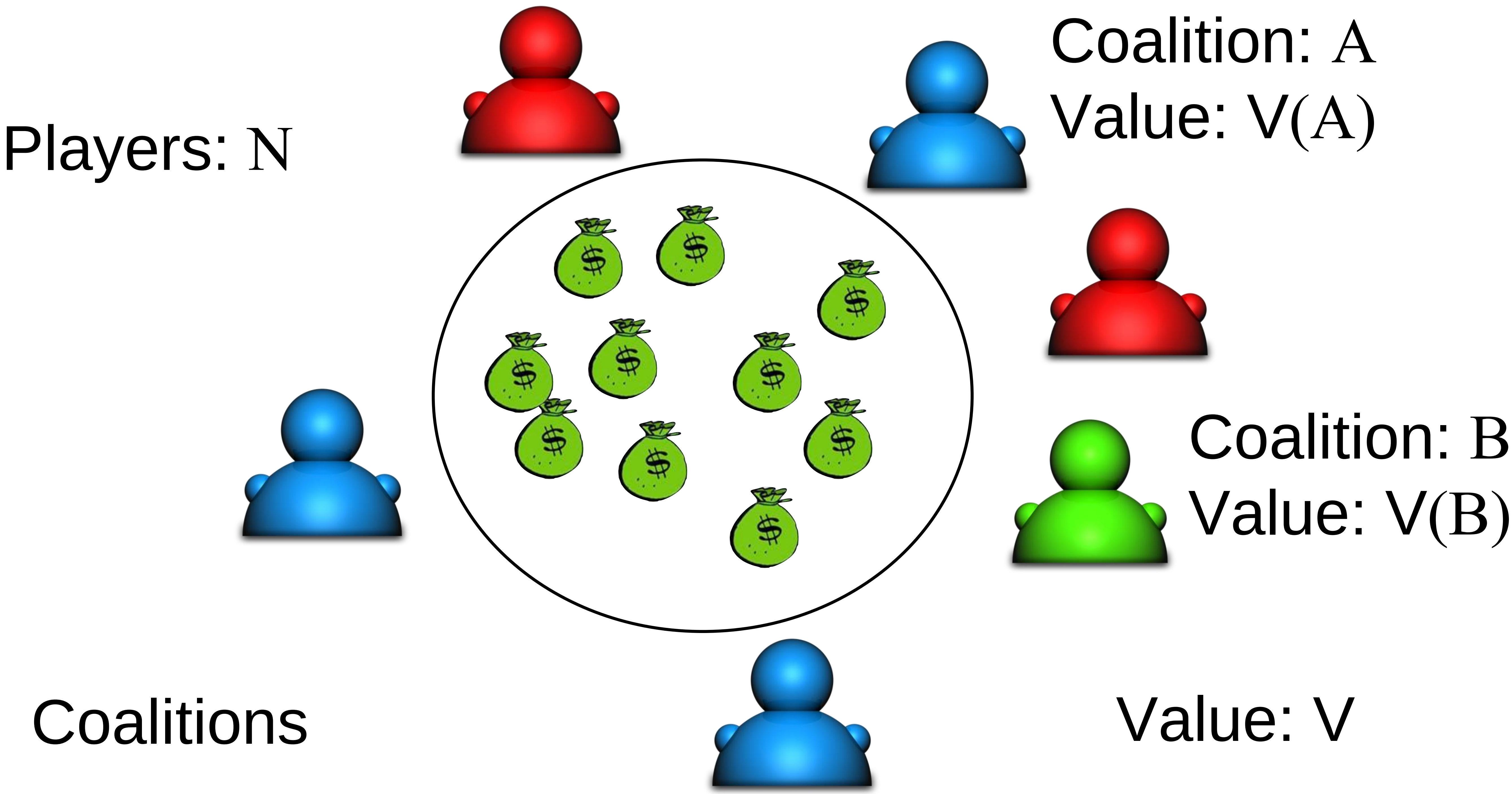


Three types of ISPs

1. **Eyeball (local) ISPs:**
   - Provide Internet access to residential users.
   - E.g. Time Warner Cable, Comcast, Verizon, AT&T, Jio, Airtel
2. **Content ISPs:**
   - Serves content providers
   - E.g. Cogent, Akamai, Level3, Netflix (Content Distribution Networks)
3. **Transit ISPs:**
   - Provide global connectivity, transit services for other ISPs.
   - E.g. Tier 1 ISPs: Level3, AT&T, Telefonica, Tata



Cooperative Games

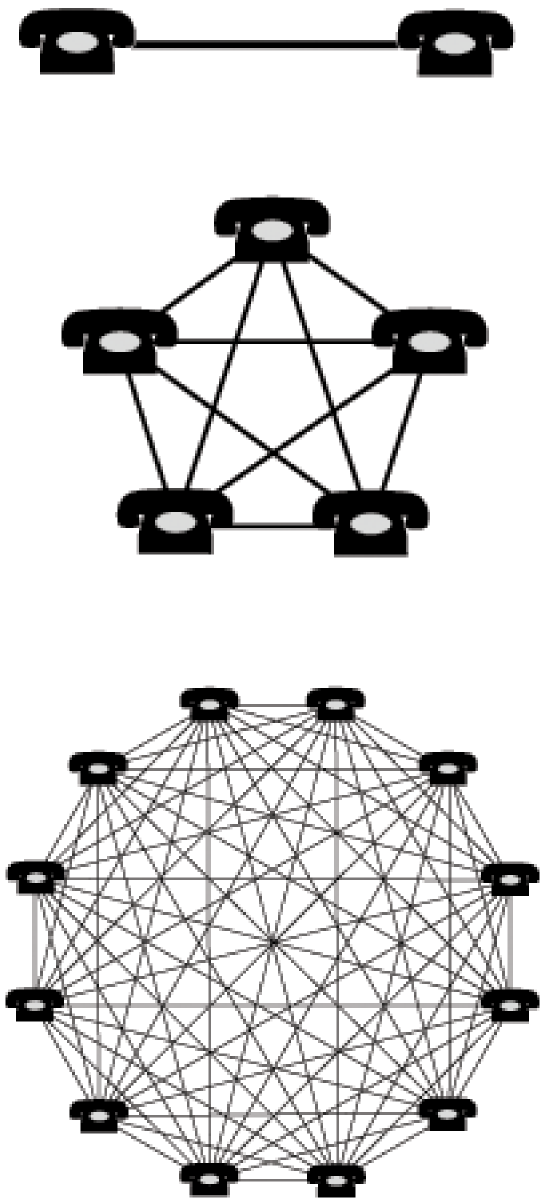


Cooperative Game Theory

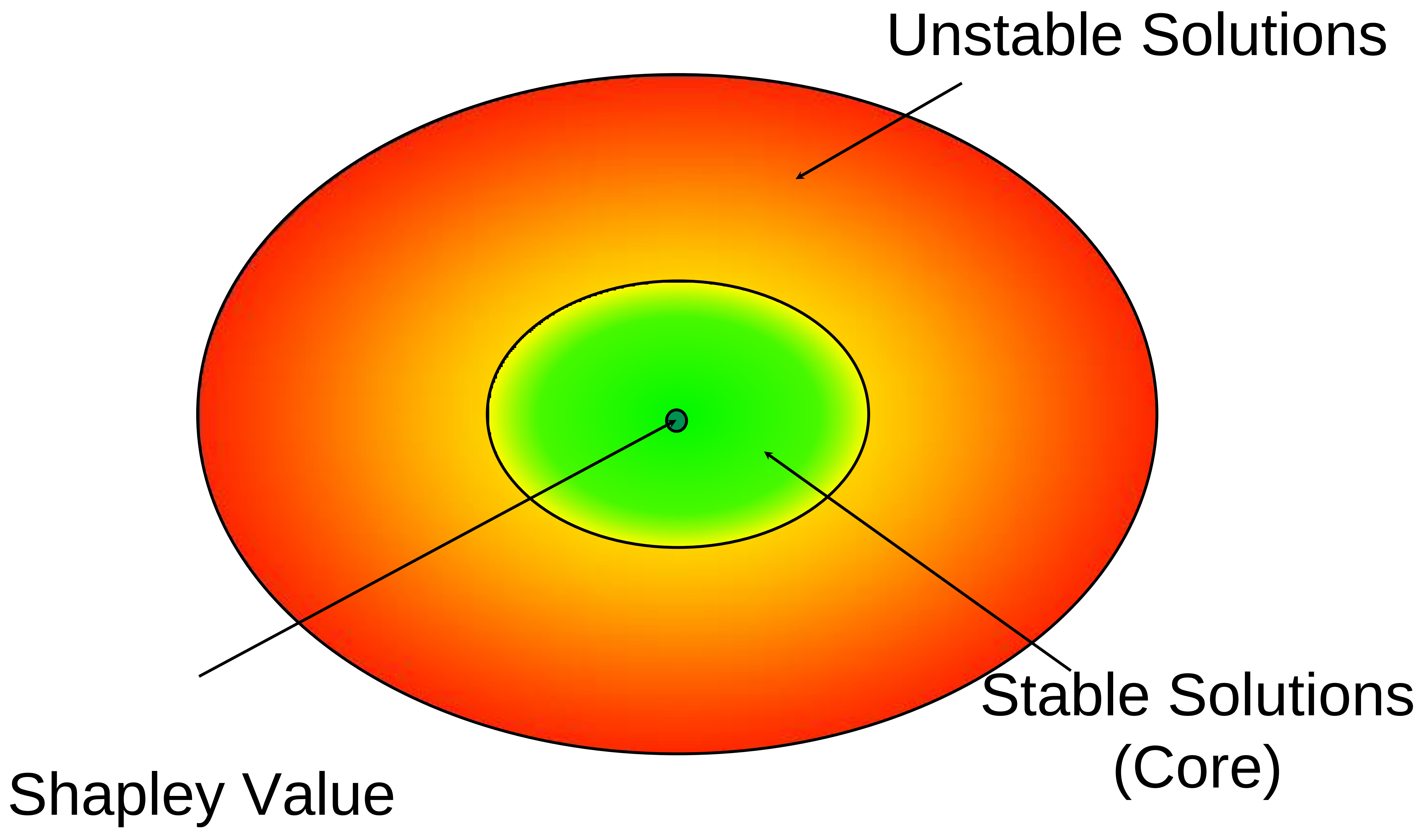
- Analyses coalition formation given value allocation
- Value allocation characterizes a solution of a game
- Some properties of interest in a solution
  - Stability: Players do not want to deviate from the solution
  - Fairness: Allocation to players reflects their contribution

Convex Games

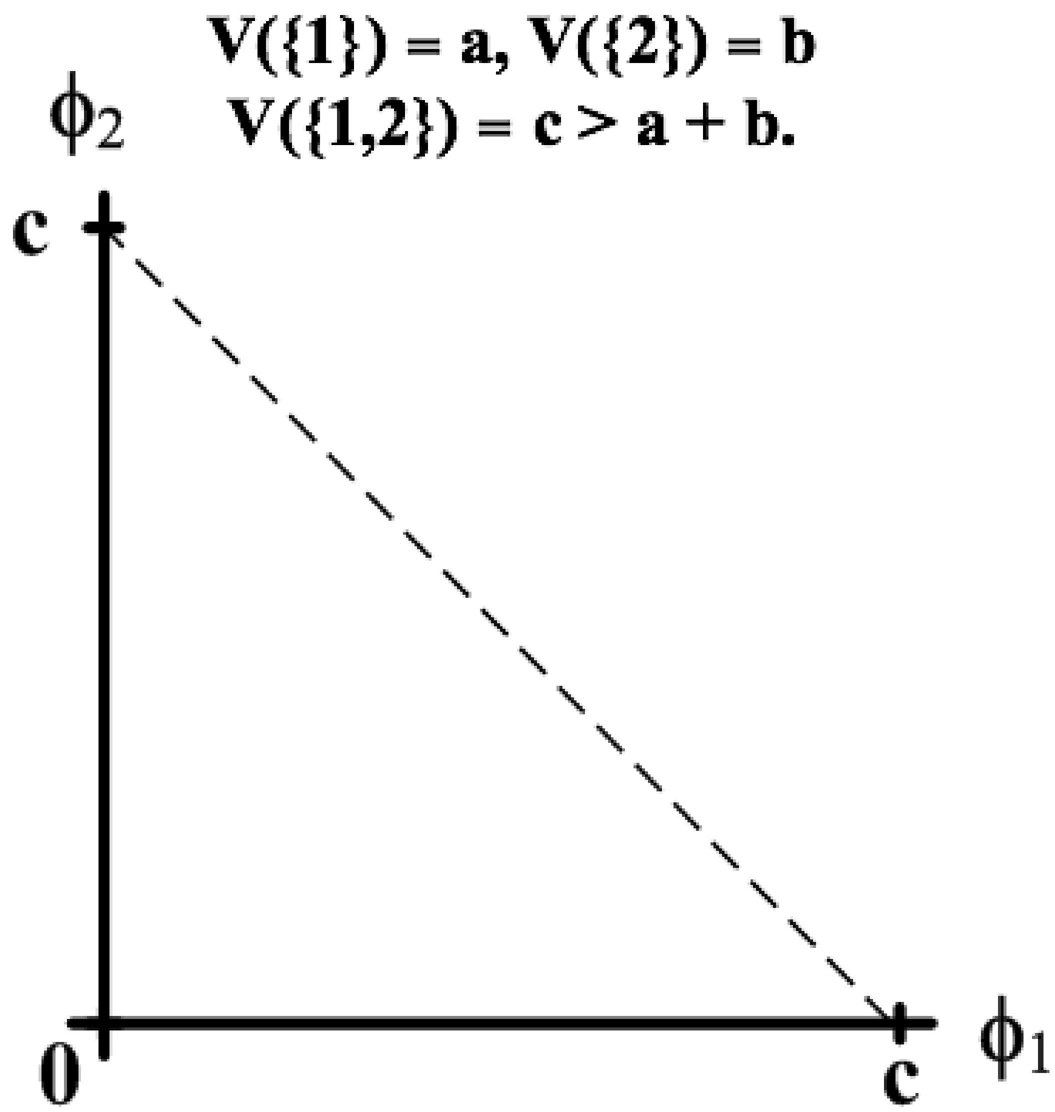
- V is Convex if for all coalitions A, B, V(A∪B)-V(B) ≥ V(A)-V(A∩B)
- Marginal contribution of a player increases with the size of the coalition it joins
- Natural model for networks
  - Metcalfe's "law" $v(n) = n^2$
  - Odlyzko's "law" V(n) = n log n



Core and Shapley Value of Convex Games

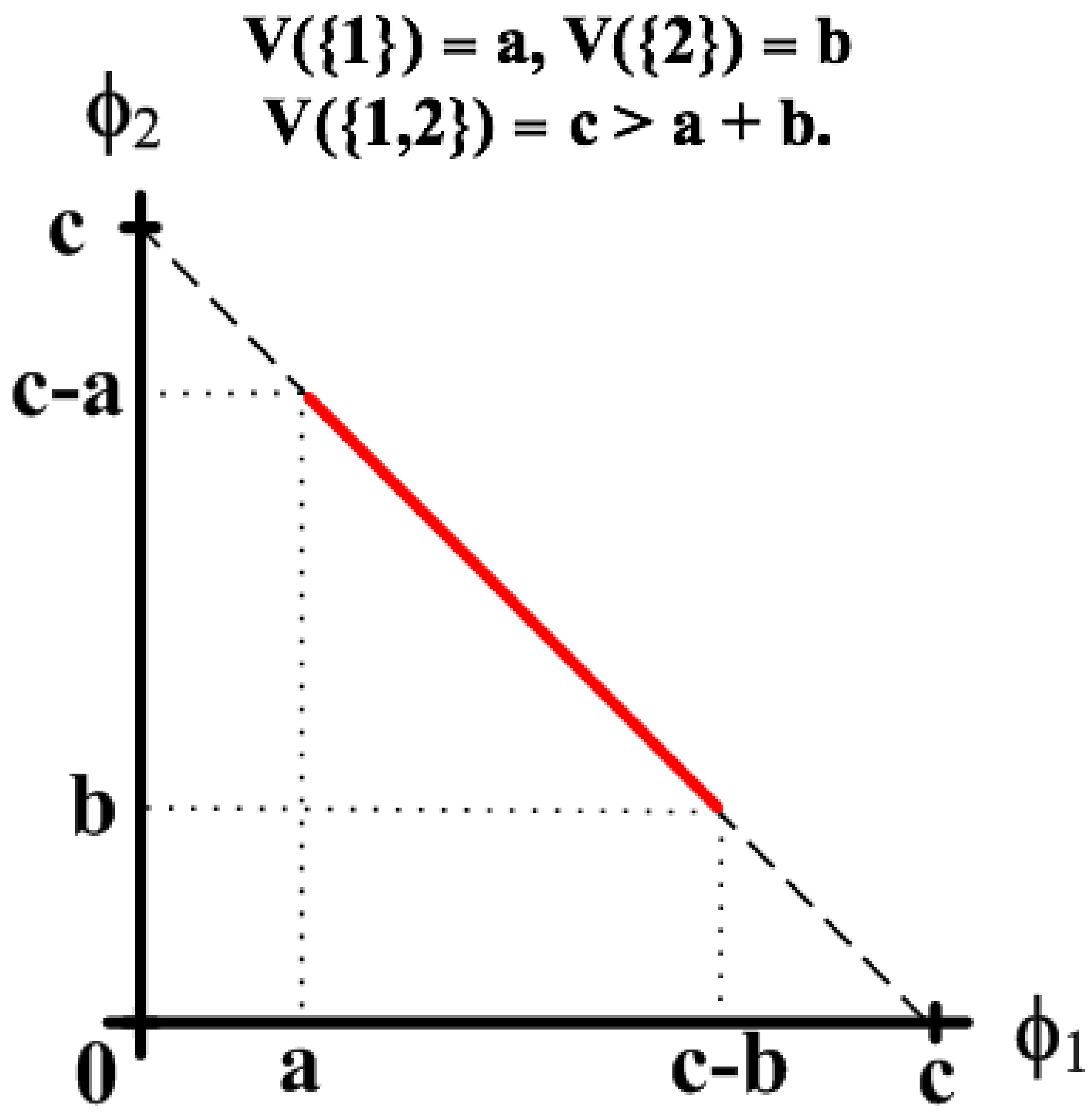


Stability of the Shapley value



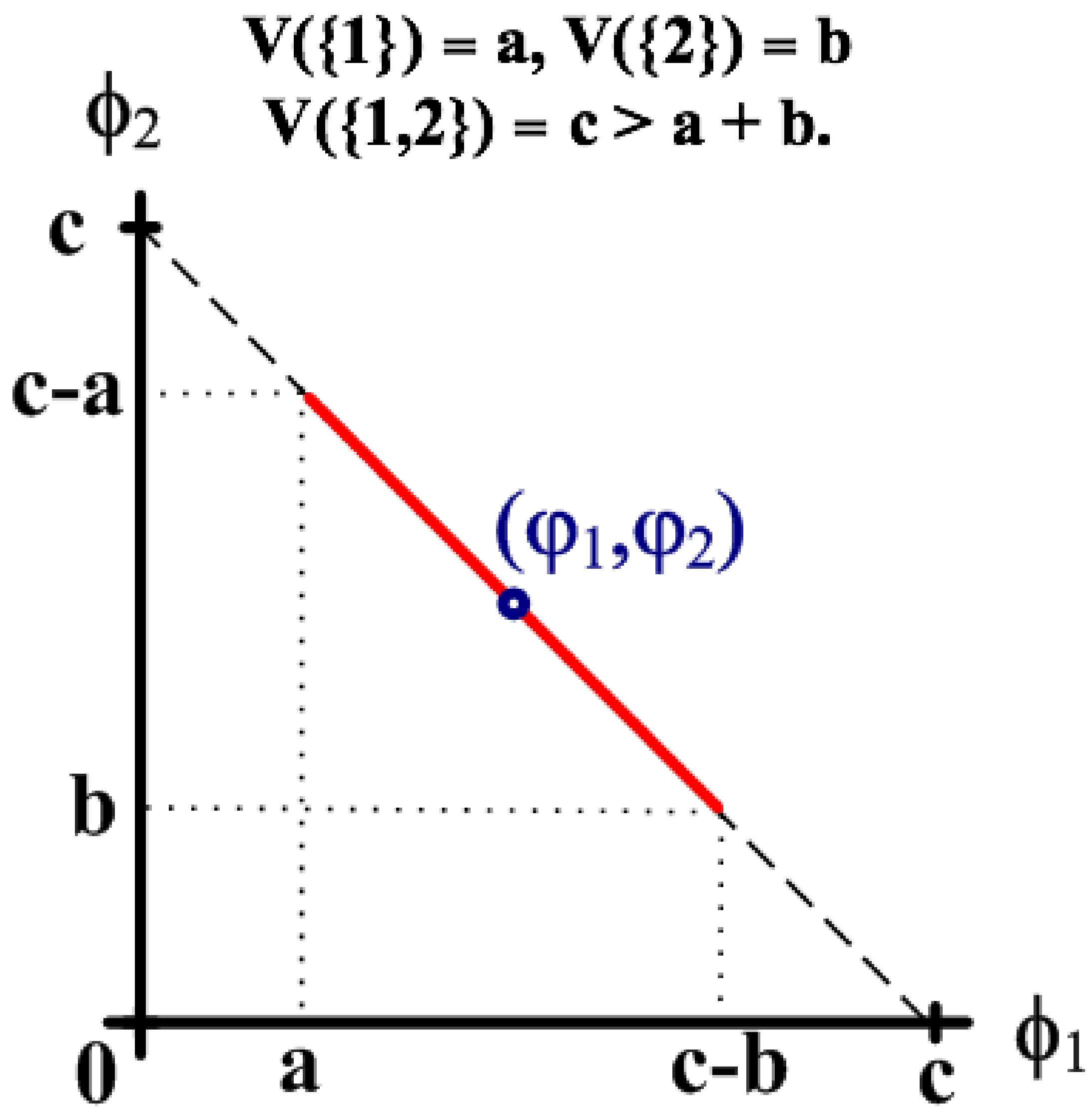
- Convex game:
  - V(SUT)>= V(S)+V(T)
  - Whole is bigger than the sum of parts.

Stability of the Shapley value



- Convex game:
  - V(SUT)>= V(S)+V(T)
  - Whole is bigger than the sum of parts.
- Core: the set of efficient profit-share that no coalition can improve upon or block.

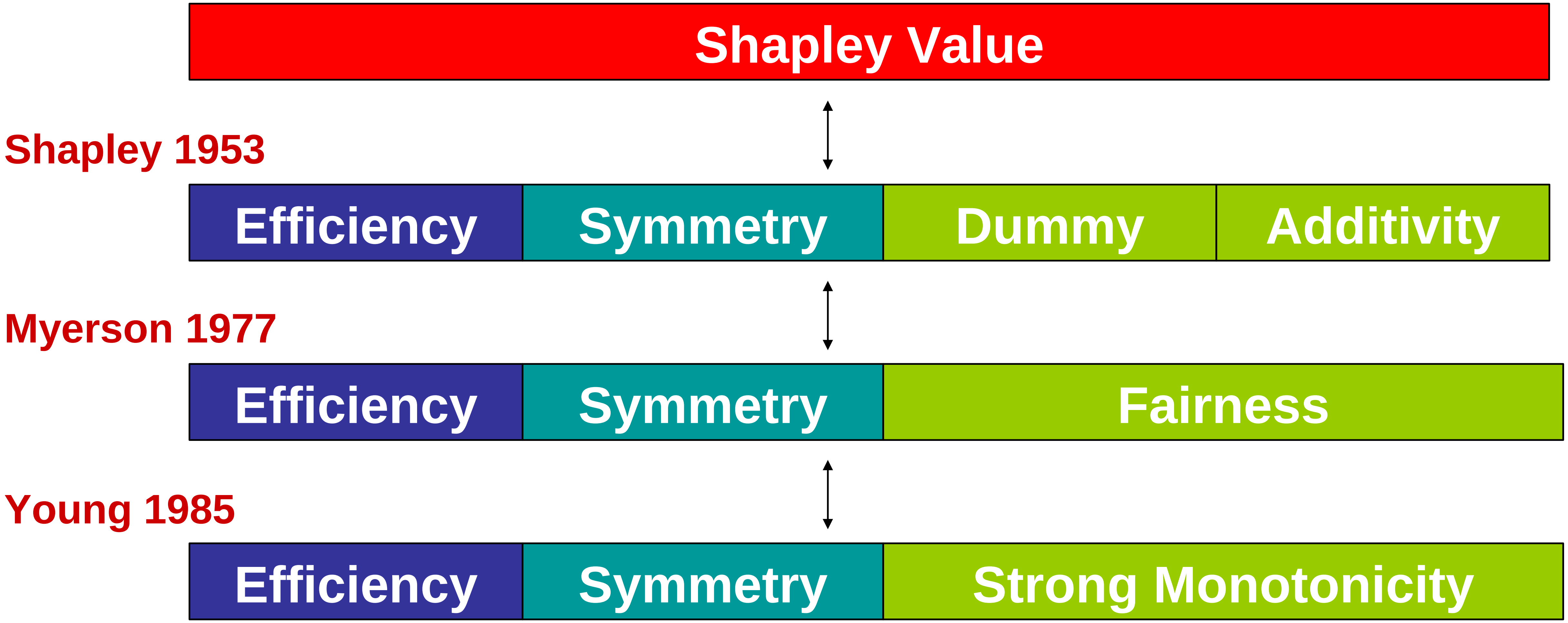
Stability of the Shapley value



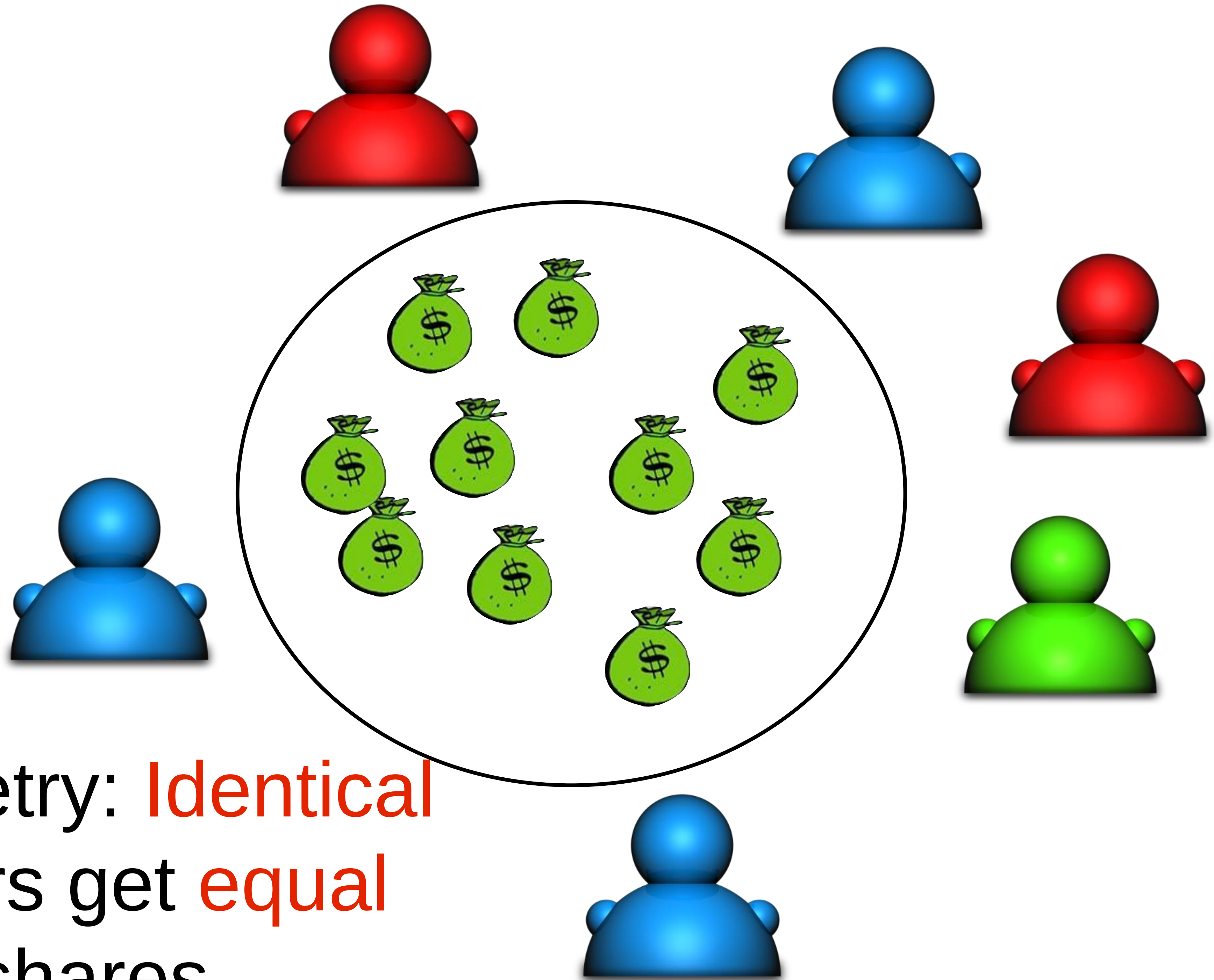
- Convex game:
  - V(SUT)>= V(S)+V(T)
  - Whole is bigger than the sum of parts.
- Core: the set of efficient profit-share that no coalition can improve upon or block.
- Shapley [1971]
  - Core is a convex set.
  - The value is located at the center of gravity of the core.

Axiomatic characterization of the Shapley value

What is the Shapley value? – A measure of one’s contribution to different coalitions that it participates in.

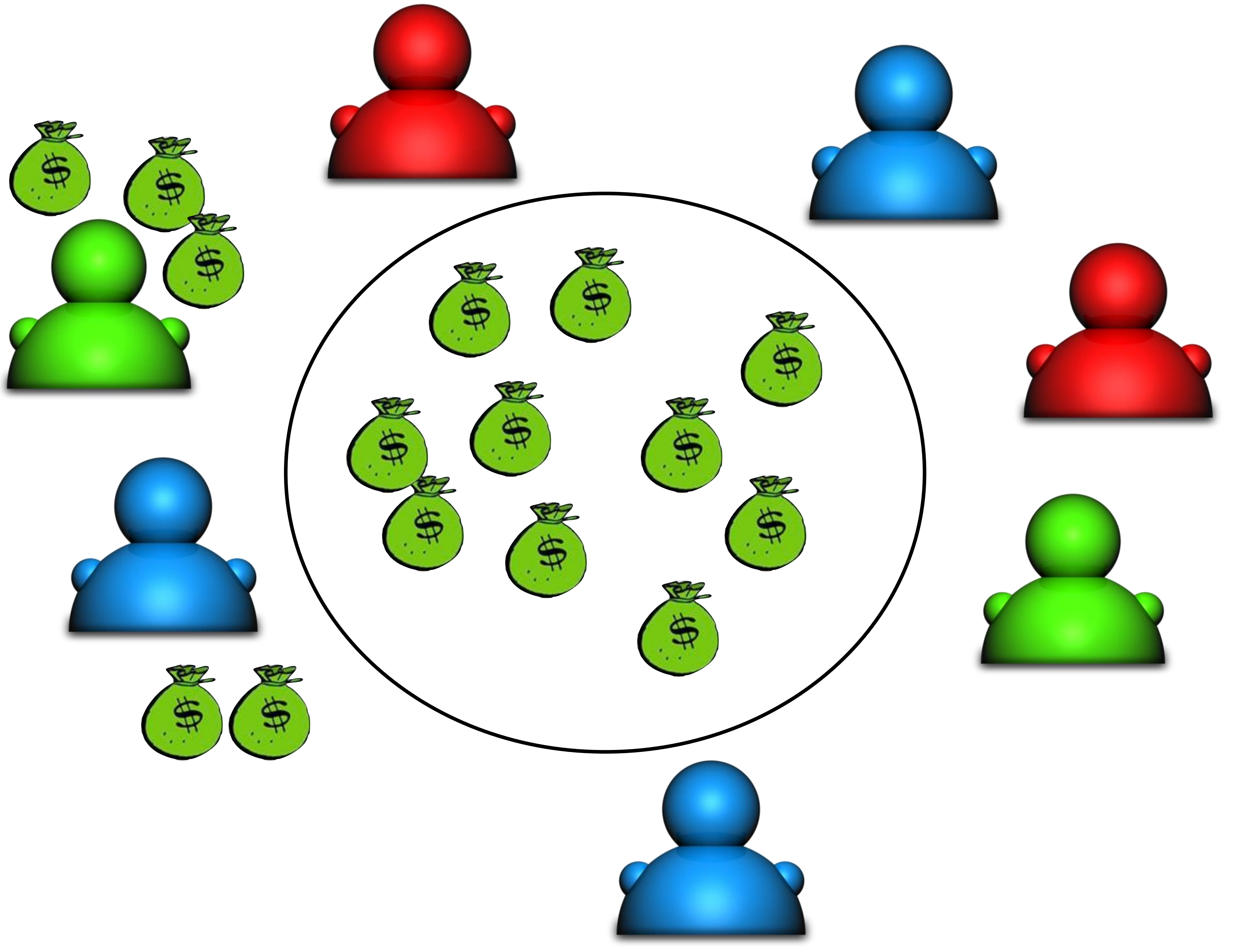


Efficiency, Symmetry

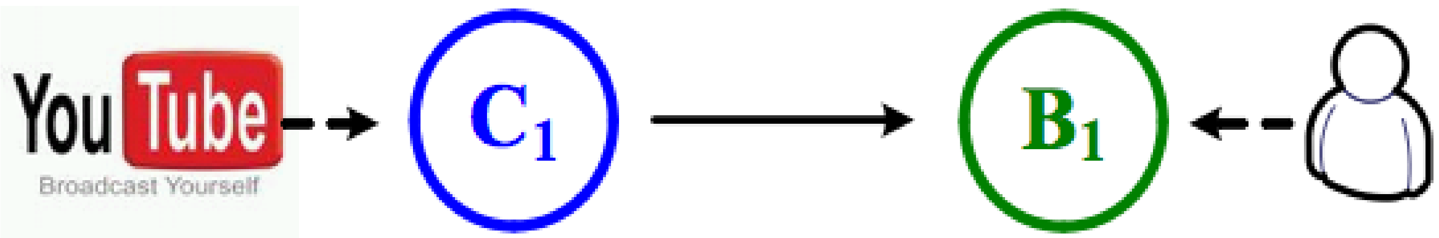


Symmetry: Identical players get equal shares

Balanced Contribution (Fairness)



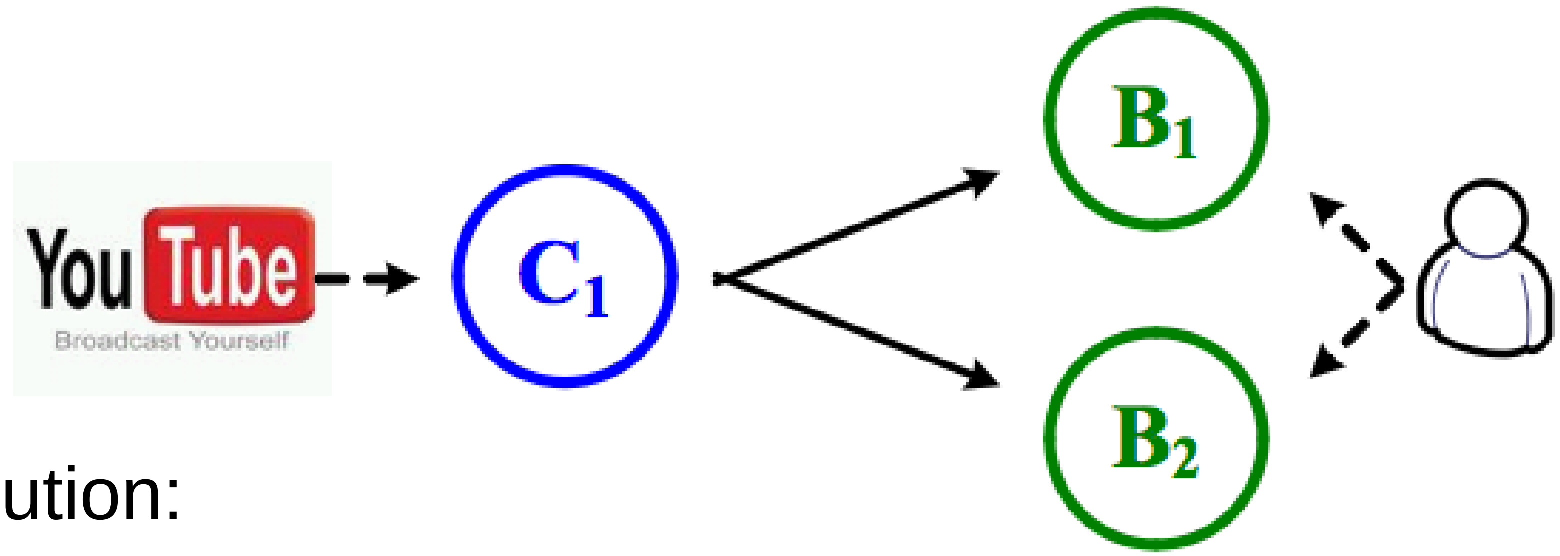
How do we share profit? -- the baseline case



- One content and one eyeball ISP
- Profit **V** = total revenue = content-side + eyeball-side
- **F**air profit sharing:

$$\varphi_{B_1} = \varphi_{C_1} = \frac{1}{2} V$$

How do we share profit? -- two symmetric eyeball ISPs



Axiomatic Solution:

- **Symmetry**: same profit for symmetric eyeball ISPs

$$\varphi_{B_1} = \varphi_{B_2} = \varphi_B$$

- **Efficiency**: summation of individual ISP profits equals V

$$\varphi_{C_1} + 2\varphi_B = V$$

- **Fairness**: same mutual contribution for any pair of ISPs

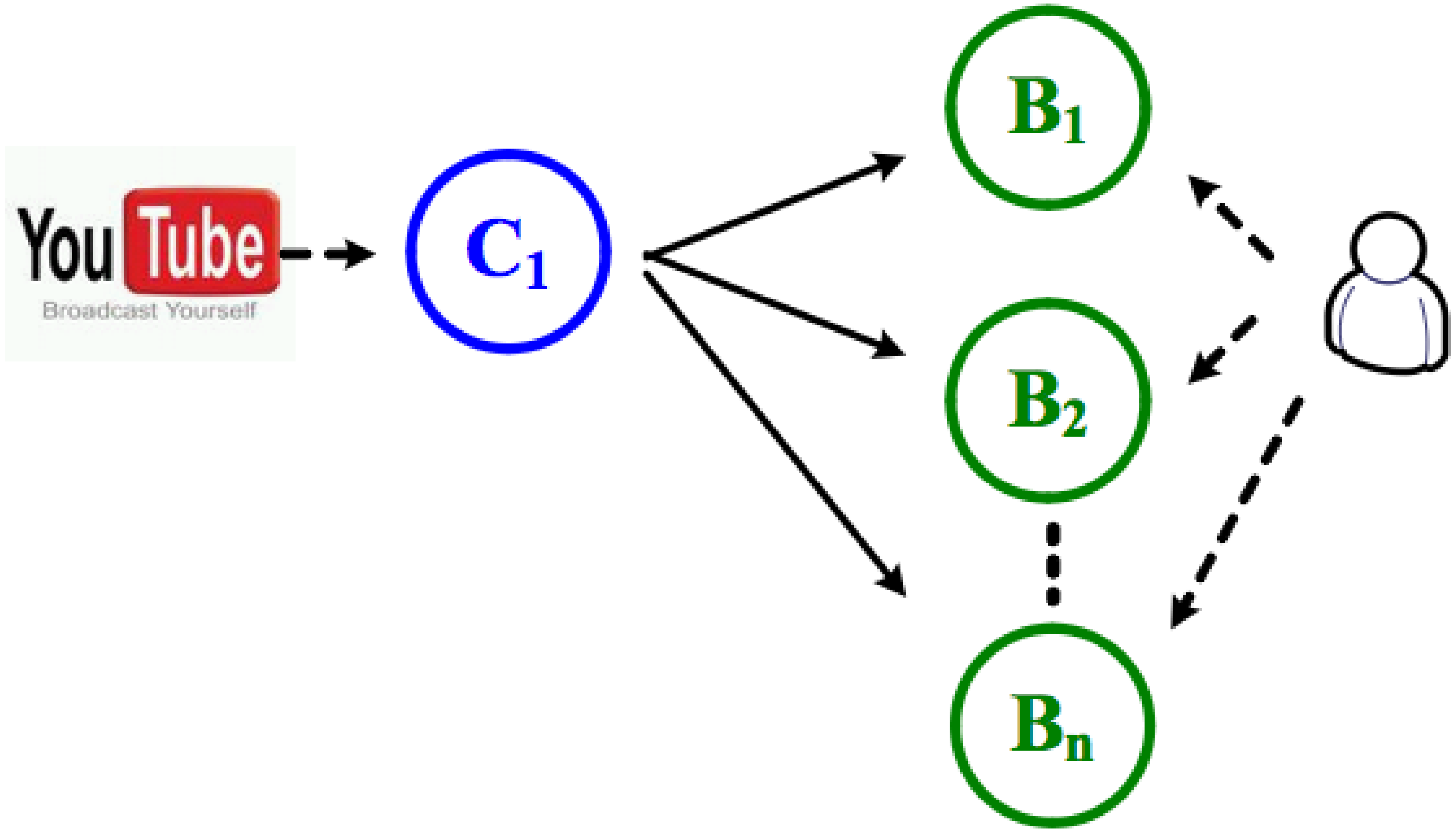
$$\varphi_{C_1} - \frac{1}{2}V = \varphi_{B_1} - 0$$

Unique solution
(Shapley value)

$$\varphi_{C_1} = \frac{2}{3}V$$

$$\varphi_B = \frac{1}{6}V$$

How do we share profit? -- n symmetric eyeball ISPs

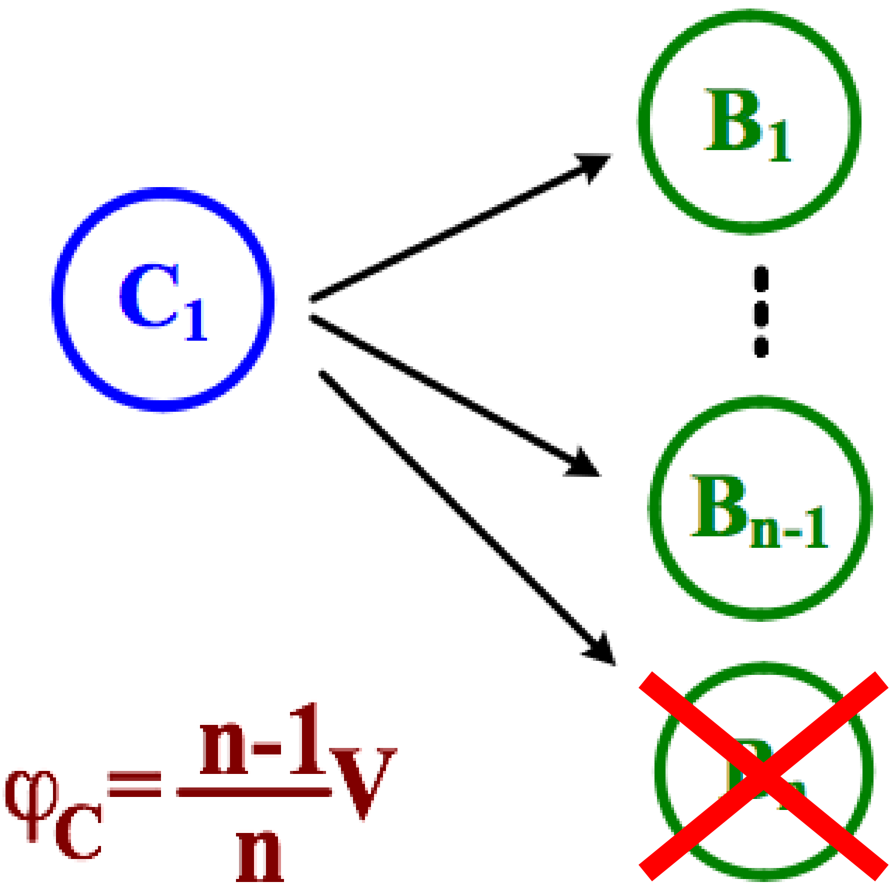


- **Theorem**: the Shapley profit sharing solution is

$$\varphi_B = \frac{1}{n(n+1)} V, \quad \varphi_C = \frac{n}{n+1} V$$

Results and implications of profit sharing

$$\varphi_B = \frac{1}{n(n+1)}V, \quad \varphi_C = \frac{n}{n+1}V$$



- With more eyeball ISPs, the content ISP gets a larger profit share.
  - Multiple eyeball ISPs provide redundancy,
  - The single content ISP has leverage.

- Content's profit with one less eyeball:
- The marginal profit loss of the content ISP:

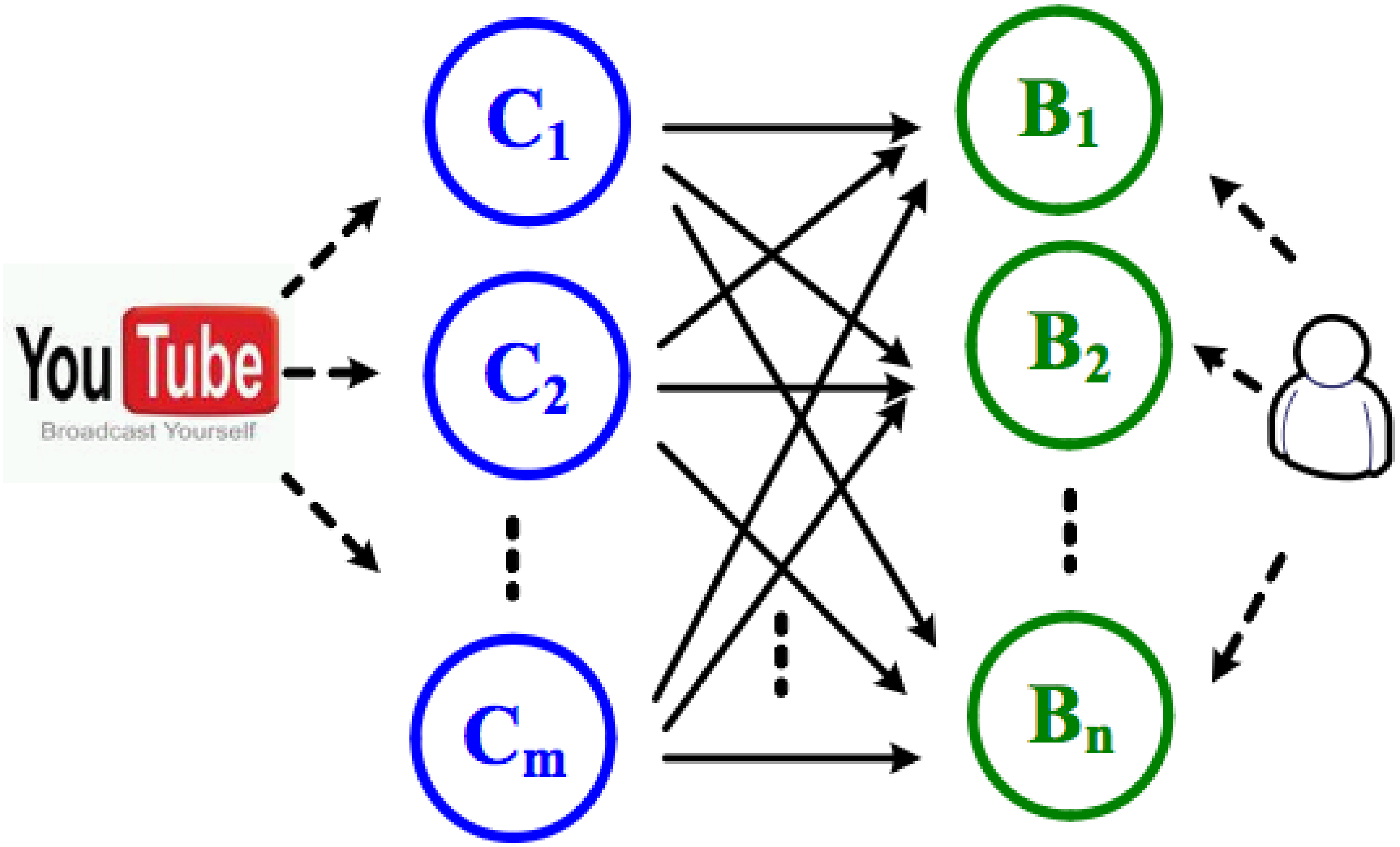
$$\varphi_C = \frac{n-1}{n}V$$

$$\Delta\varphi_C = \frac{n-1}{n}V - \frac{n}{n+1}V = -\frac{1}{n^2}\varphi_C$$

If an eyeball ISP leaves

- The content ISP will lose $1/n^2$ of its profit.
- If n=1, the content ISP will lose all its profit.

Profit share -- multiple eyeball and content ISPs

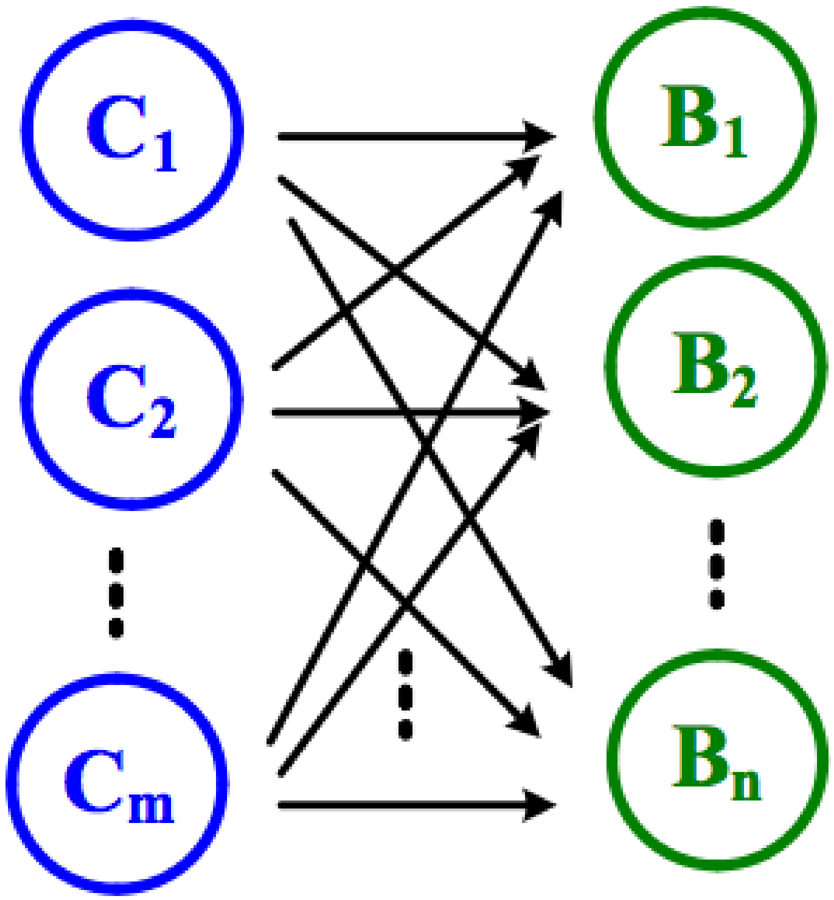


- **Theorem**: the Shapley profit sharing solution is

$$\varphi_B = \frac{m}{n(n+m)} V, \quad \varphi_C = \frac{n}{m(n+m)} V$$

Results and implications of ISP profit sharing

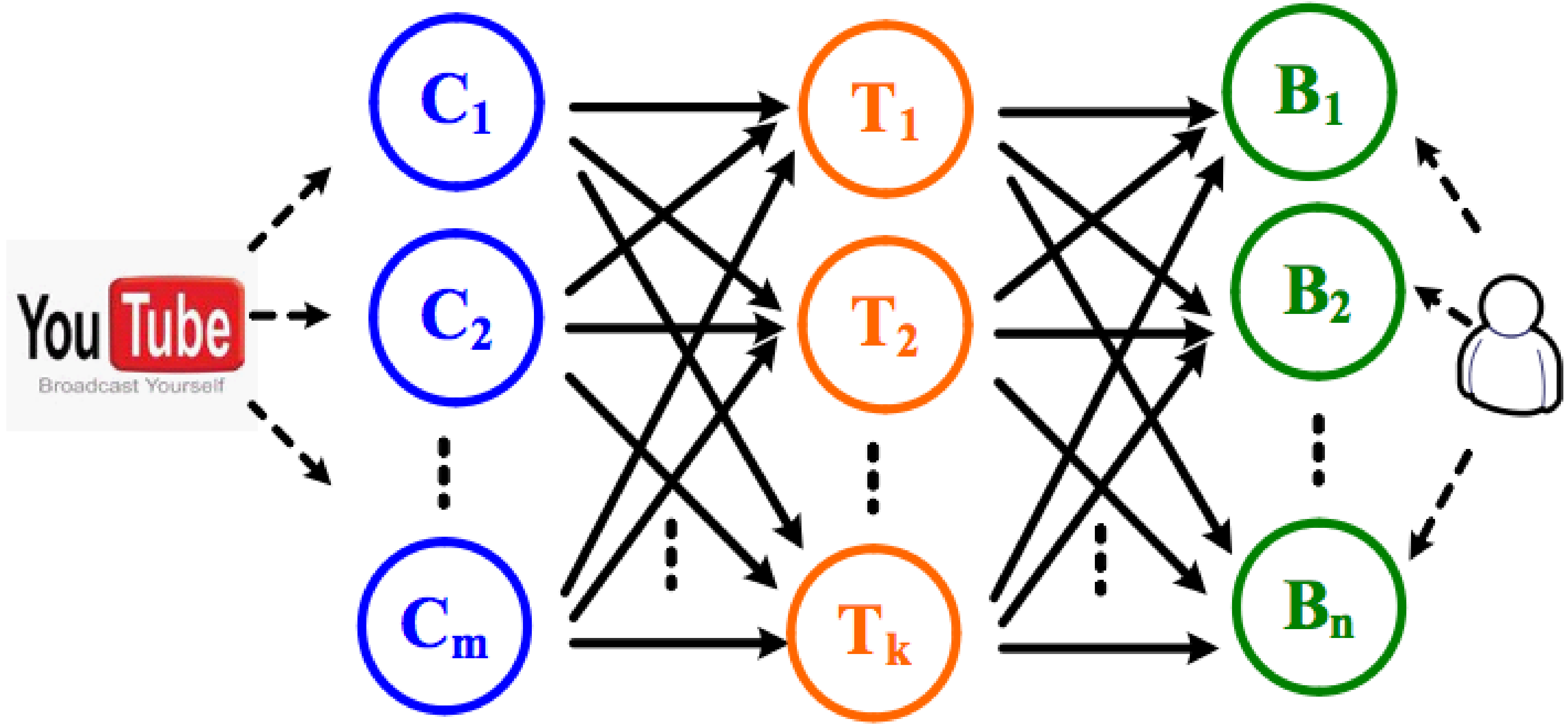
$$\varphi_B = \frac{m}{n}\frac{V}{(n+m)}, \varphi_C = \frac{n}{m}\frac{V}{(n+m)}$$



- **Each ISP's profit share is**
  - Inversely proportional to the number of ISPs of the same type.
  - Proportional to the number of ISPs of the other type.

- **Intuition**
  - When more ISPs provide the same service, each of them obtains less bargaining power.
  - When fewer ISPs provide the same service, each of them becomes more important.

Profit share -- eyeball, transit and content ISPs



- **Theorem**: the Shapley profit sharing solution is

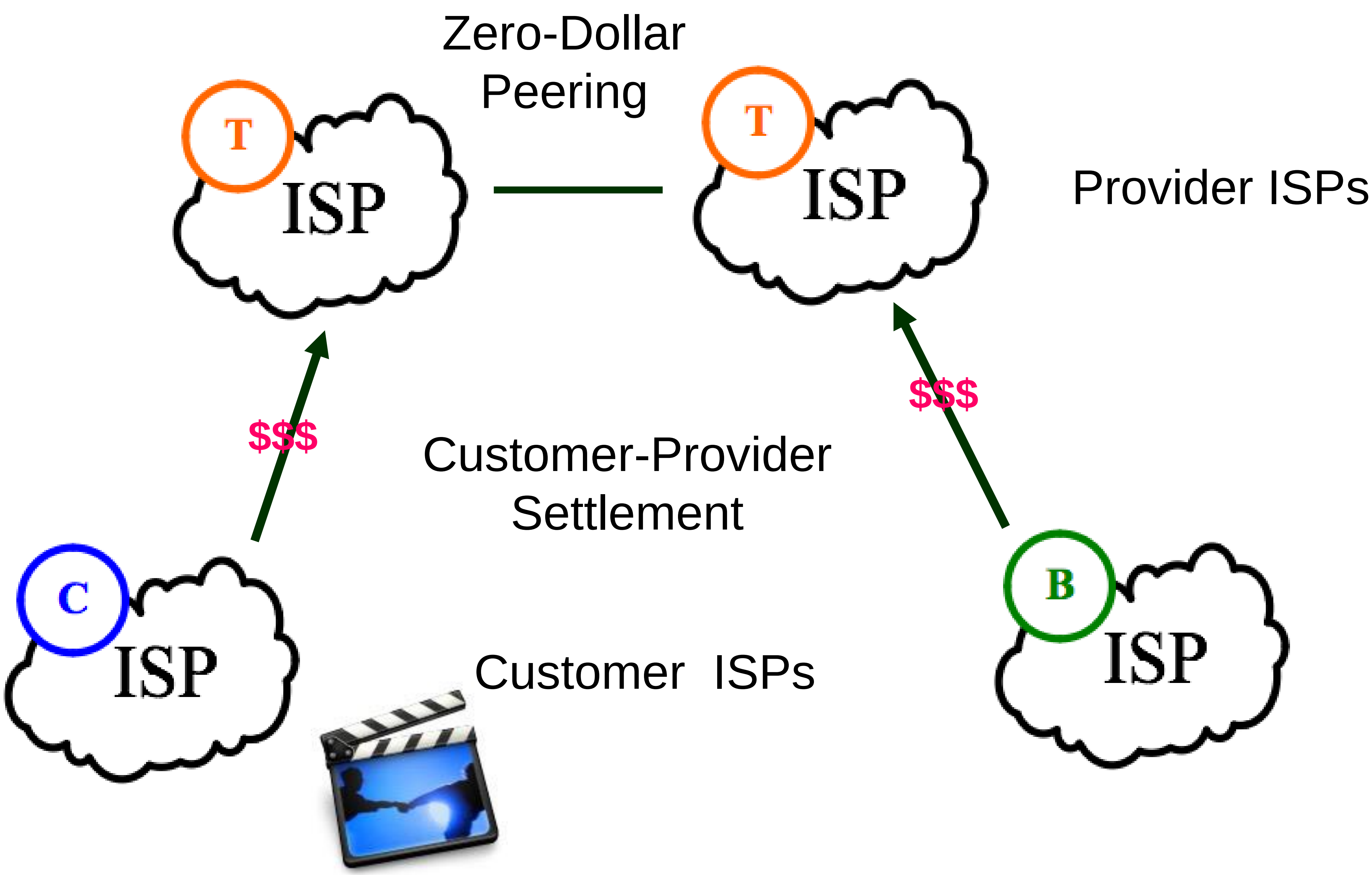
$$\varphi_B = \frac{V}{n+m+k} \sum_{\mu=1}^{m} \sum_{\kappa=1}^{k} \binom{m}{\mu} \binom{k}{\kappa} \binom{n+m+k-1}{\mu+\kappa}^{-1}$$

$$\varphi_C = \frac{V}{n+m+k} \sum_{\nu=1}^{n} \sum_{\kappa=1}^{k} \binom{n}{\nu} \binom{k}{\kappa} \binom{n+m+k-1}{\nu+\kappa}^{-1}$$

$$\varphi_T = \frac{V}{n+m+k} \sum_{\mu=1}^{m} \sum_{\nu=1}^{n} \binom{m}{\mu} \binom{n}{\nu} \binom{n+m+k-1}{\mu+\nu}^{-1}$$

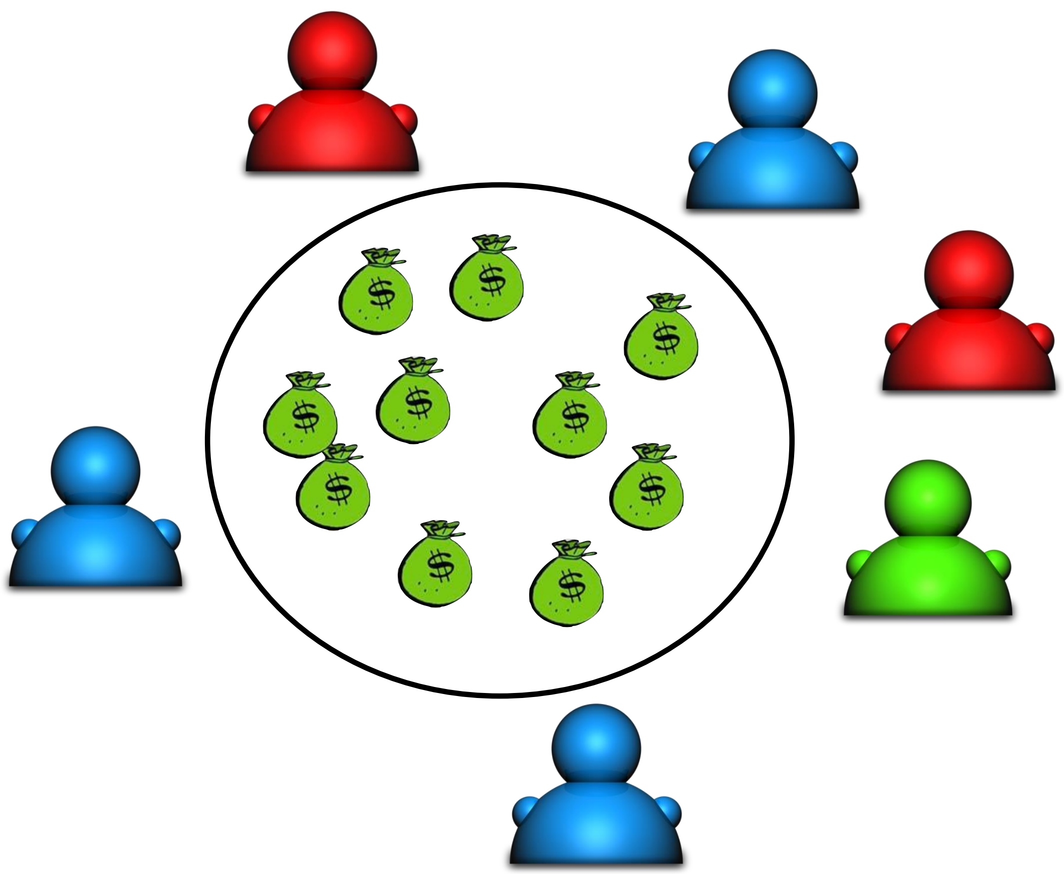
Common ISP Business Practices: A Macroscopic View

Two forms of bilateral settlements:

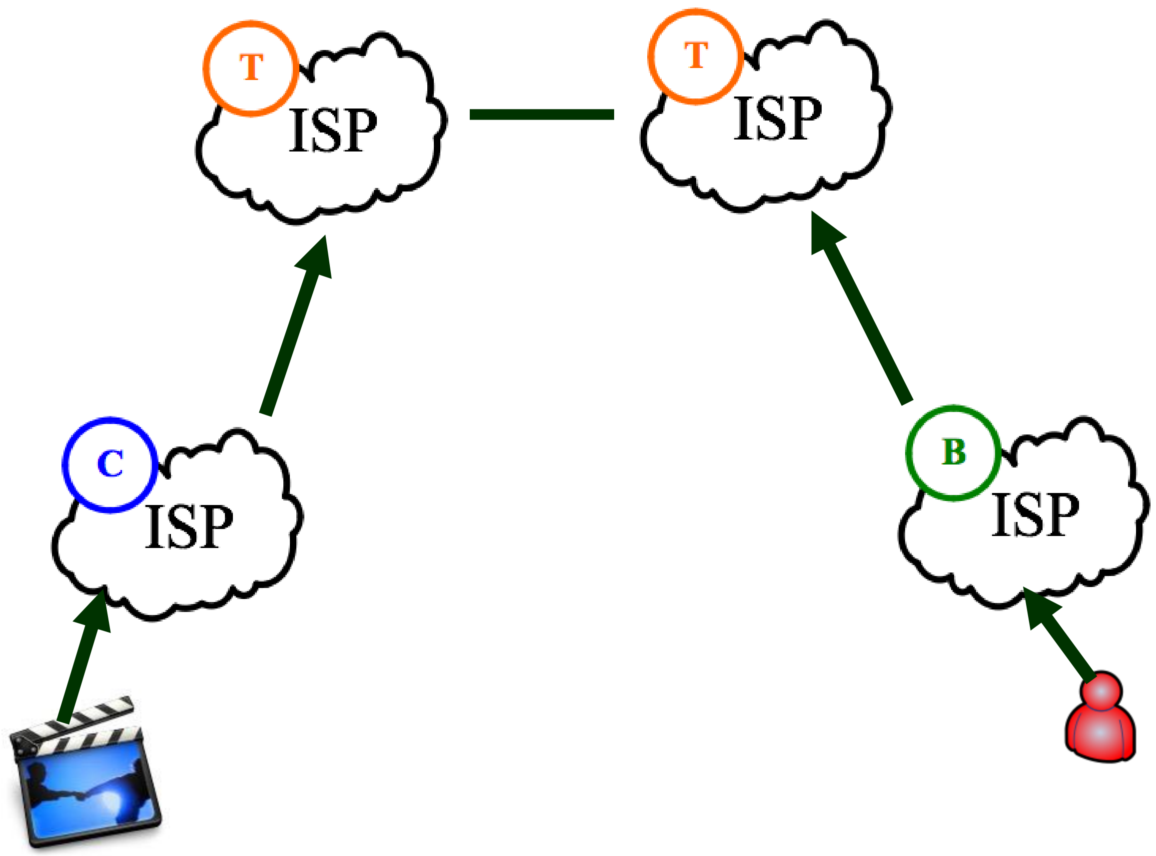


Achieving A Stable Solution: Theory v Practice

Shapley



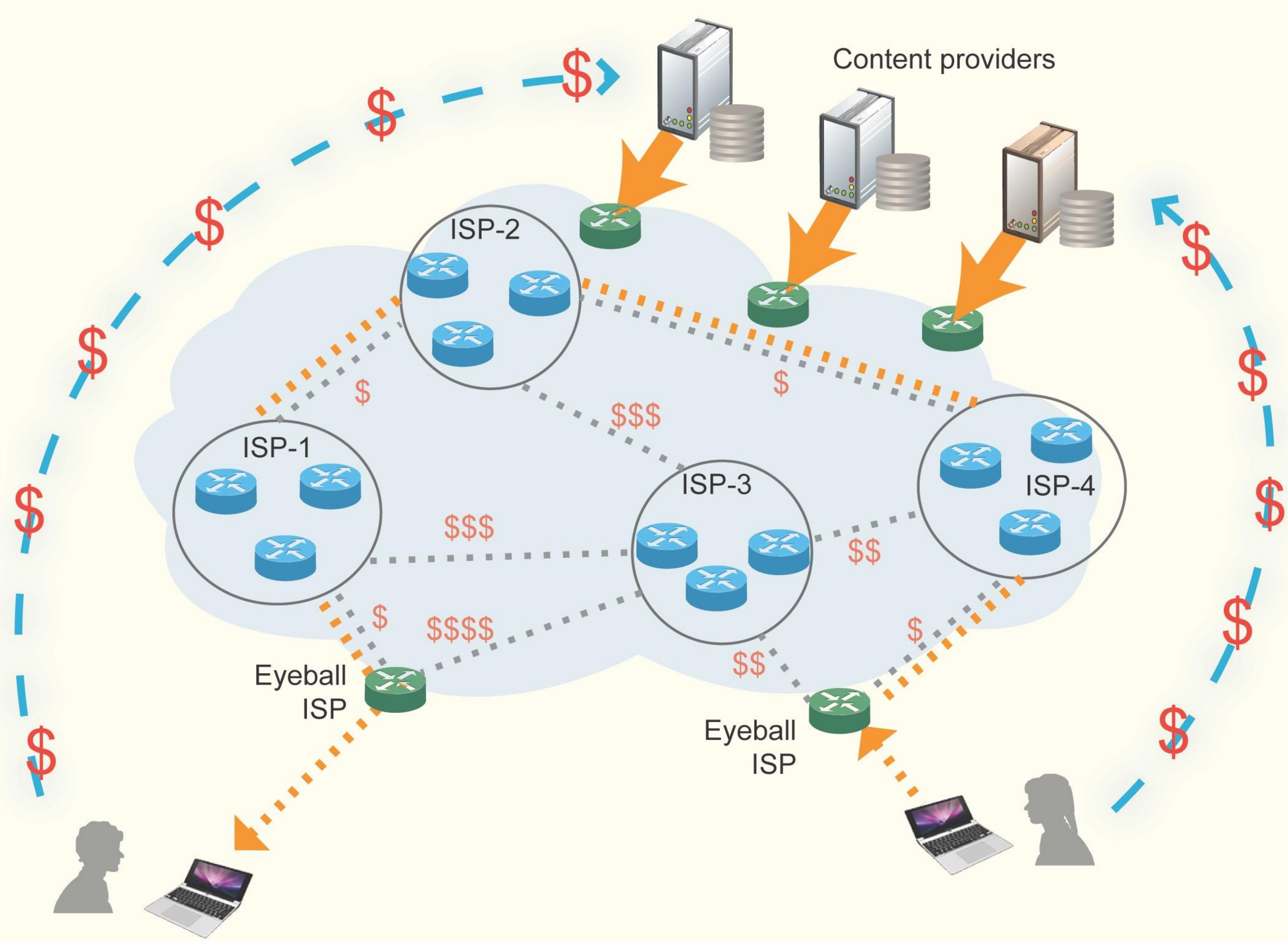
Reality



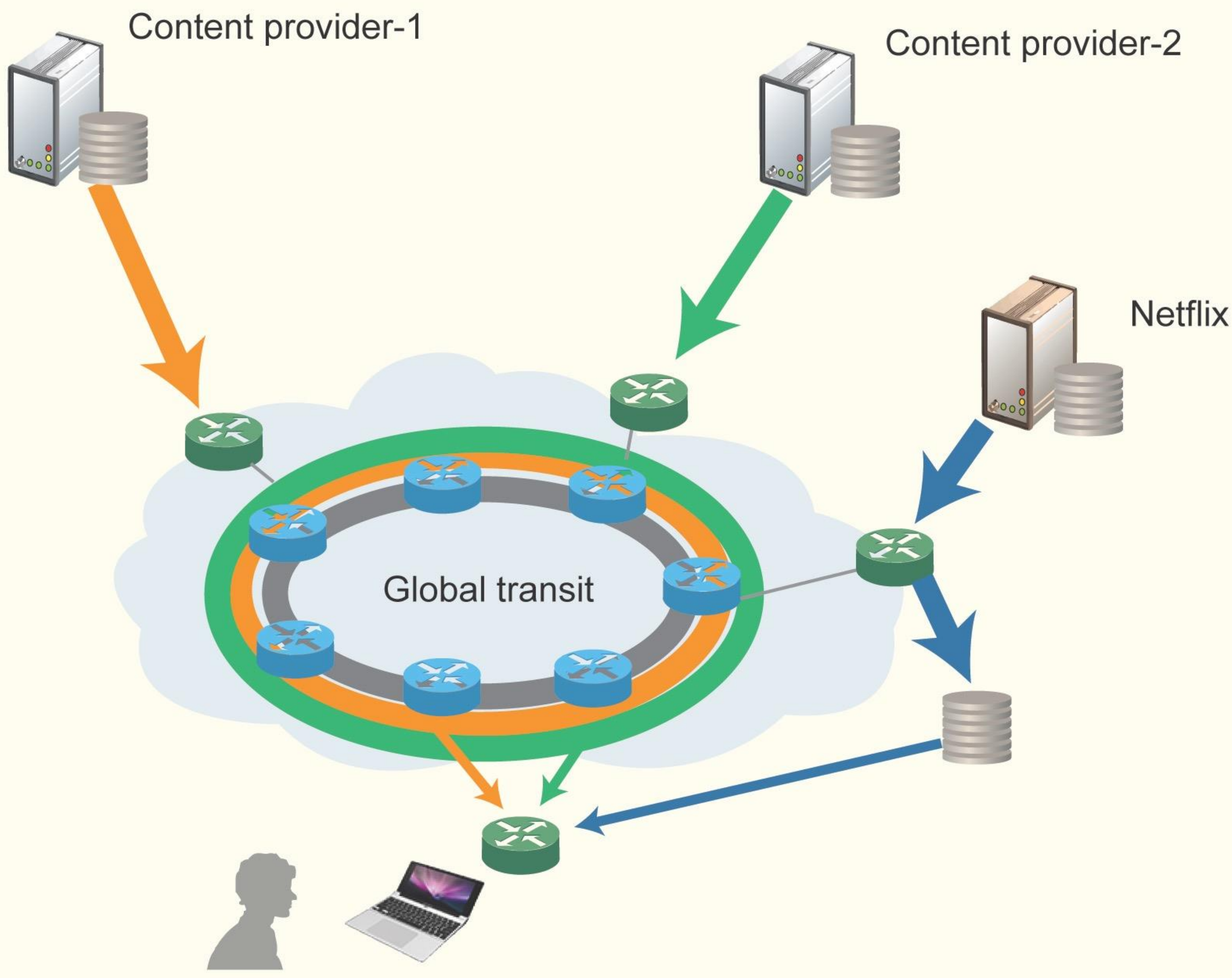
Implications

- **When CR ≈ BR, bilateral implementations:**
  - Customer-Provider settlements (Transit ISPs as providers)
  - Zero-dollar Peering settlements (between Transit ISPs)
  - Common settlements can achieve fair profit-share for ISPs.
- **If CR >> BR, bilateral implementations:**
  - ***Reverse Customer-Provider*** (Transits compensate Eyeballs)
  - ***Paid Peering*** (Content-side compensates eyeball-side)
  - New settlements are needed to achieve fair profit-share.
- **When Customer Side Competition << Content Side Competition**
  - **Paid Peering Will Dominate**

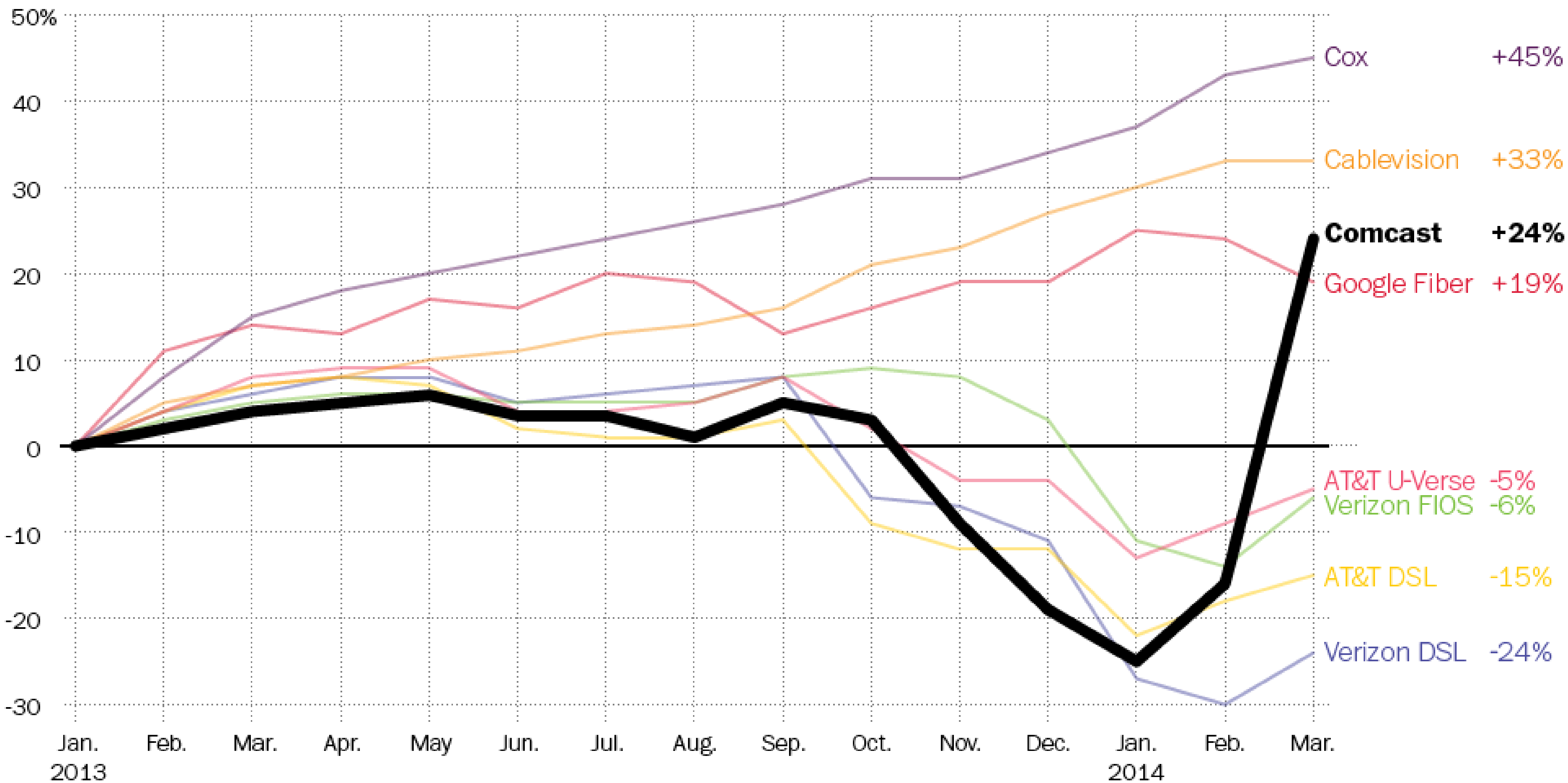
Revenue sources within and outside the Internet



Netflix-Comcast deal



% change in Netflix download speed since Jan. 2013, by I.S.P.



SOURCE: Netflix
GRAPHIC: The Washington Post. Published April 24, 2014

Competition

- Competition model in the US is broken
  - Competition is *facilities* based: everyone digs their own last mile. Inefficient, first mover has huge advantage.
- Competition in the UK, Nordic countries, far east is *service* based. Last mile is publicly/third party owned, ISPs lease access
  - ISPs compete based on performance, not by digging the first last mile

FCC definition of Net Neutrality*

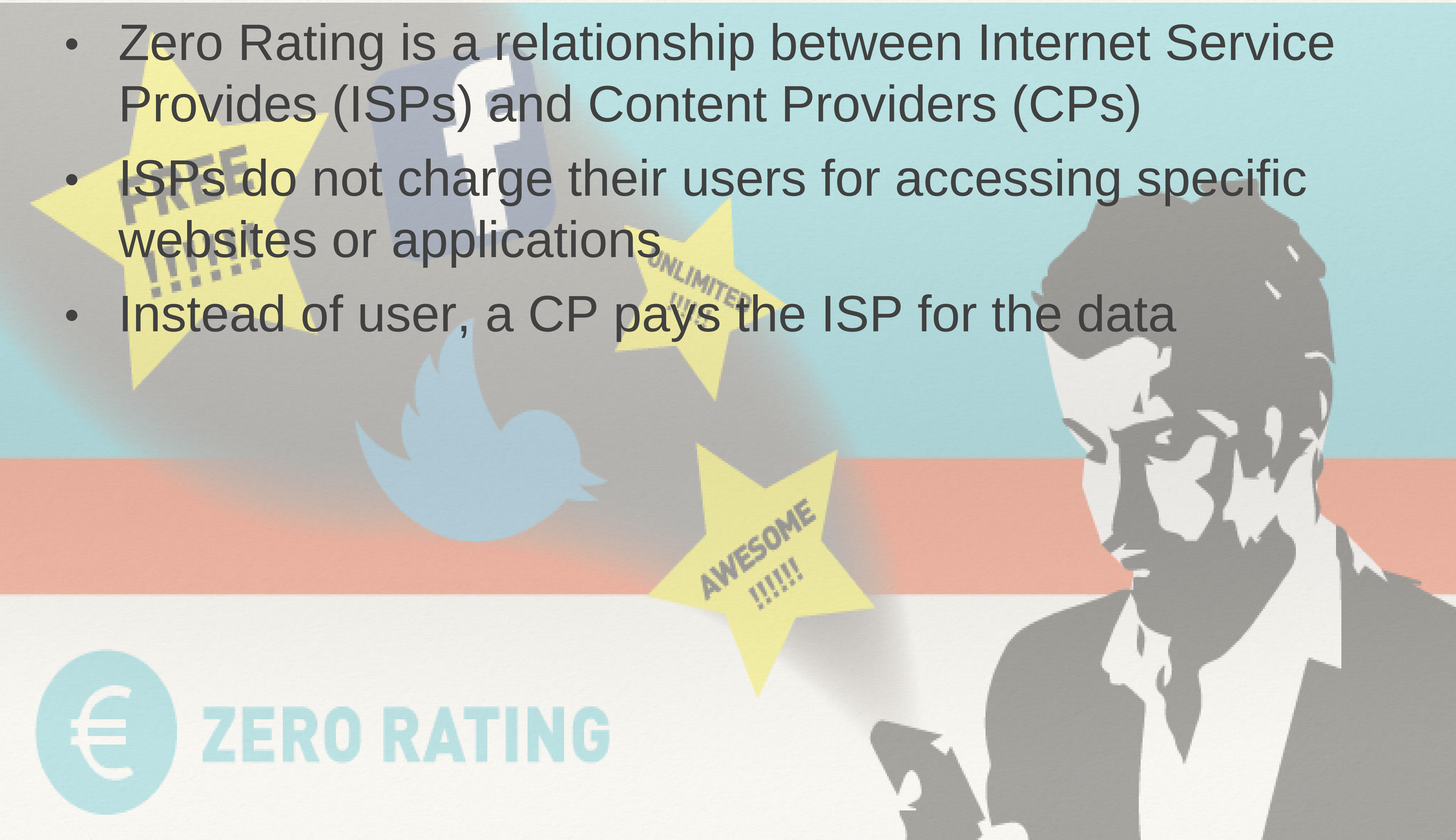
- There should be no blocking, throttling or paid prioritization (fast lanes) of any content by ISPs

* gone as of December 14, 2017

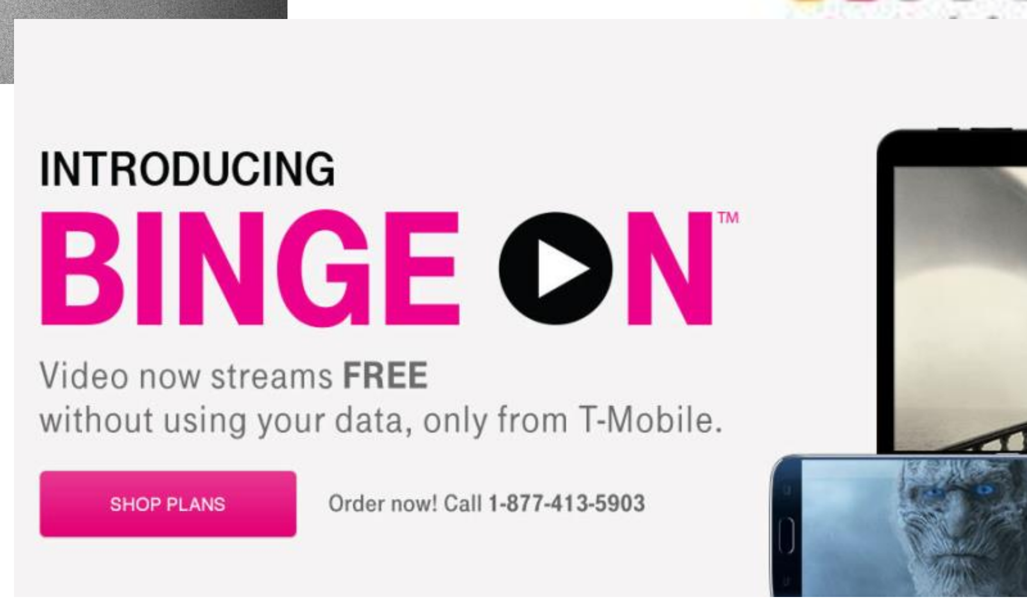
Zero Rating (and Differential Pricing)

Zero Rating

- Zero Rating is a relationship between Internet Service Provides (ISPs) and Content Providers (CPs)
- ISPs do not charge their users for accessing specific websites or applications
- Instead of user, a CP pays the ISP for the data



Examples of Zero-rating



~80 countries currently offer zero-rating type of services (not complete lis

[1] *https://en.wikipedia.org/wiki/Facebook_Zero*

[2] *https://wikimediafoundation.org/wiki/Mobile_partnerships*

Zero Rating and Consumer Surplus

- Consumer Surplus: Difference between what a consumer is *willing* to pay and what the the consumer *has* to pay (*Utility*-*Price*)
- Consumers choose commodity that gives them the most surplus
- Willingness to pay is property of content (quality, QoS etc.). FCC's definition (no blocking, throttling or paid prioritization) keeps willingness intact
- FCC silent on what consumer *has* to pay. Zero rating distorts consumer surplus and hence the market

Real World Data

- T-Mobile introduced the Binge On program in November 2015. Partner sites (Netflix, Hulu, HBO etc.) have videos Zero Rated, non-partners (YouTube etc.) not

- All videos are throttled down to 1.5 Mbps

- Two separate studies on impact of Binge On. One by T-Mobile, another by a consulting firm engaged by T-Mobile.

- T-Mobile claims Binge On *benefits everybody*

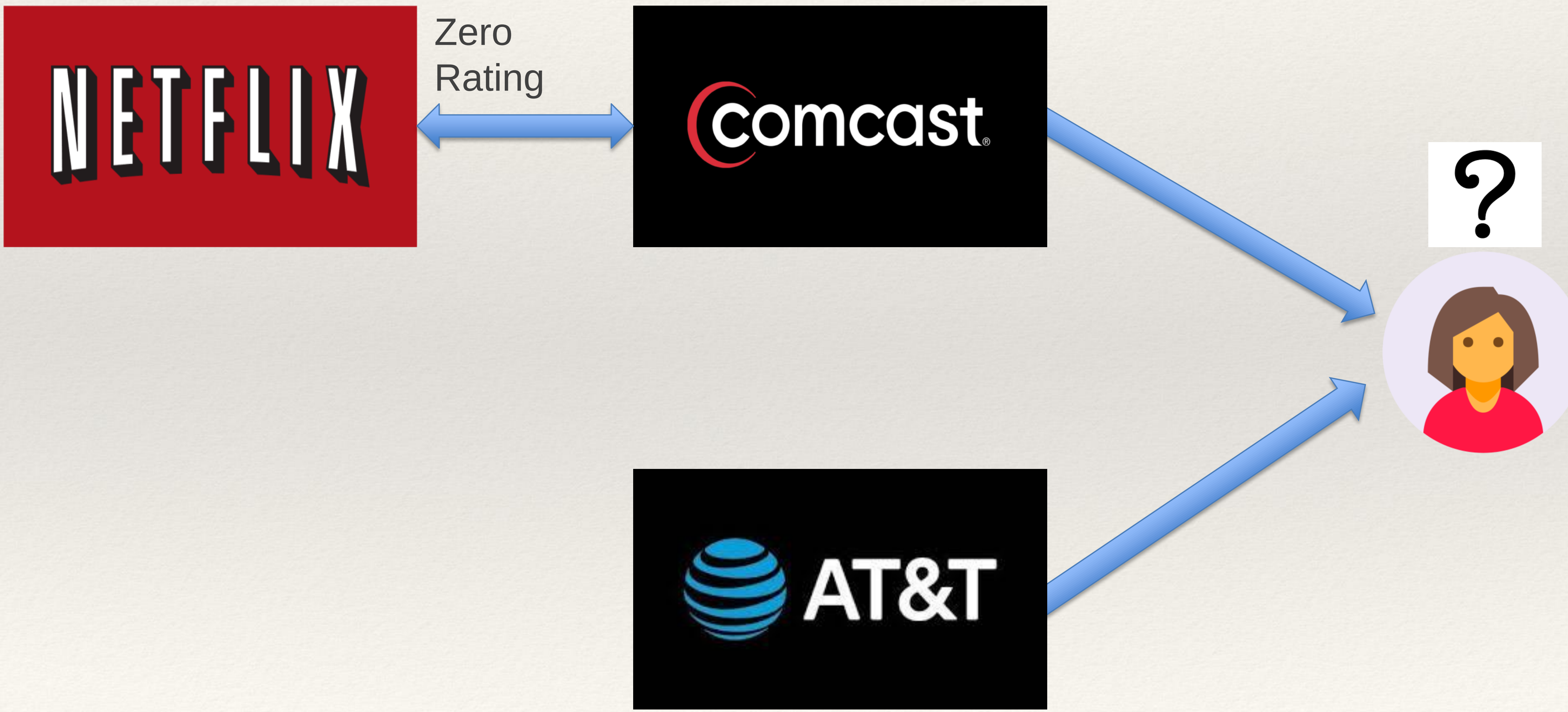
Results

- Consulting firm study: Partners showed an increase in average viewing time of 50%; the viewership of the most prominent non-partner, YouTube, increased by 16%.
- T-Mobile numbers: 79% benefit for partners, and 33% benefit for non-partners.
- Consumer Surplus isn't just theory. Market distortion is *real*

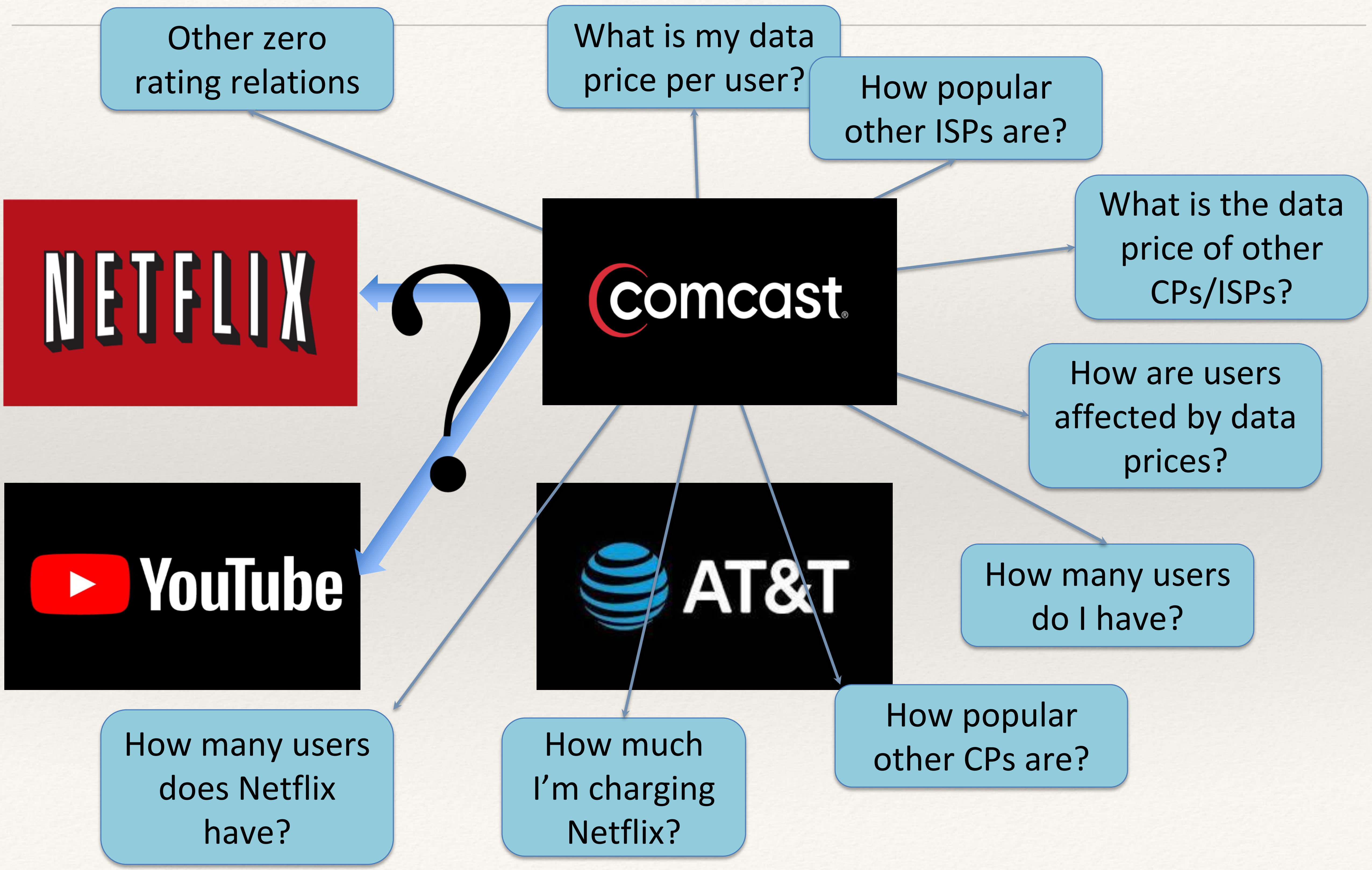
Formal Analysis

- Both ISPs and CPs decide whether to adopt zero rating
- Consumer surplus impacts users' decisions, and consequently ISP/CP's incomes
- A user model for each pair of ISP-CP is defined, based on which the market could reach *zero rating equilibrium*
- CPs might make decisions under zero rating pressure
- We numerically analyze the decisions and consequent incomes of ISPs/CPs in a monopolistic ISP market and a duopolistic market of providers.
- We analyze Herfindahl index of CP market to observe the market competition with and without zero rating.

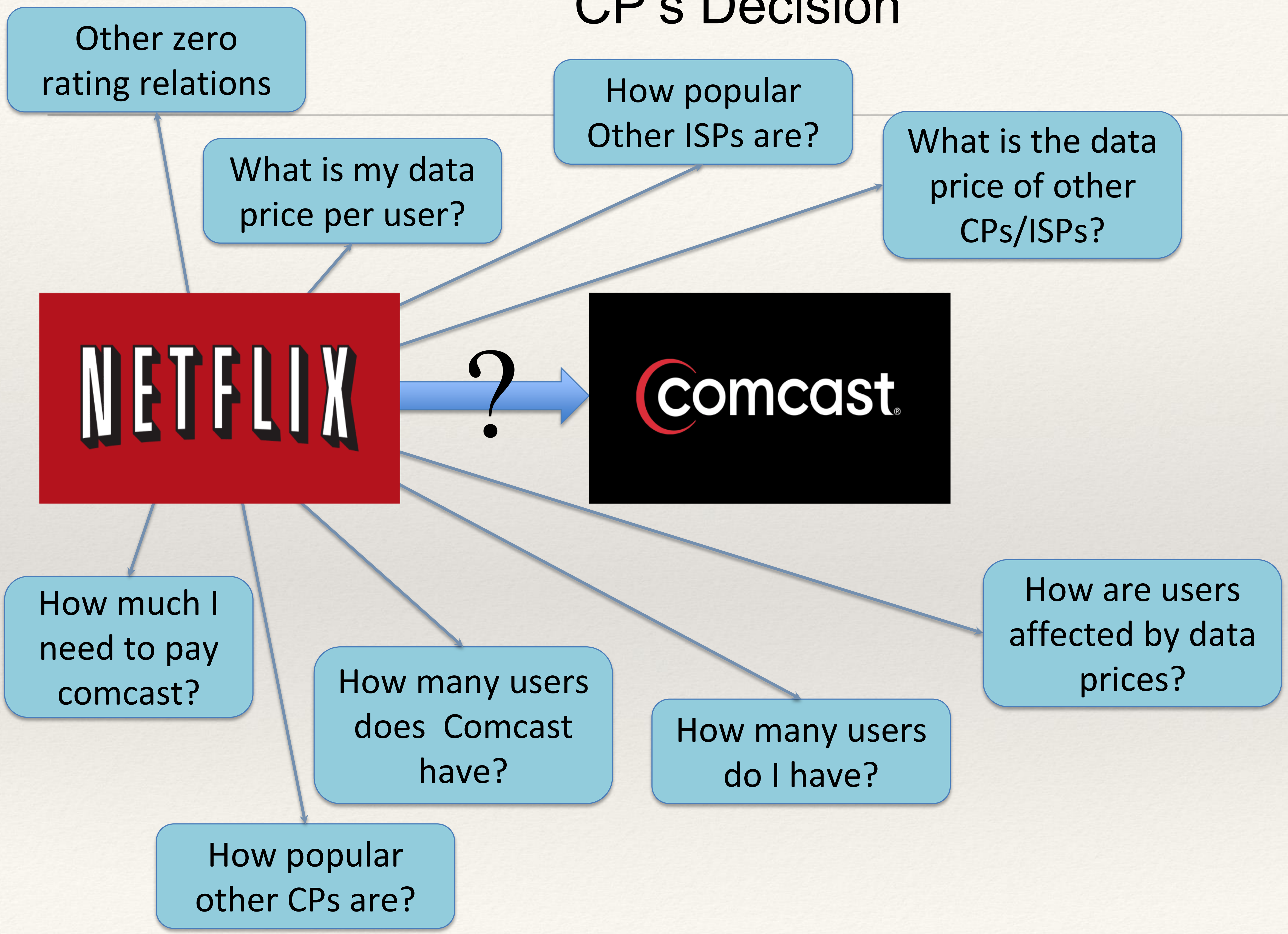
User Decision



ISP's Decision



CP's Decision



Choice Model

The probability of choosing i from a set S can be computed using *Luce's Choice Axiom*:

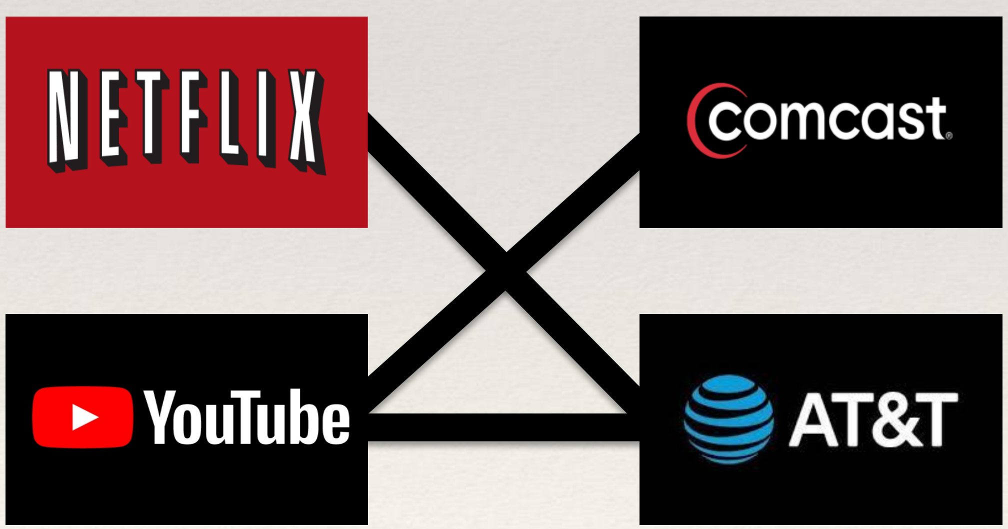
$$P_S(i) = \frac{W_i}{\sum_{j \in S} W_j}$$

- Suppose we have a set $\mathcal{N}$ of CPs and $\mathcal{M}$ of ISPs.
- In practice, users may choose services from constrained sets of CPs and ISPs.
  - certain providers are not available to the users or cannot satisfy their requirements.
  - denote a set of choice pairs by L
- By extending Luce's choice axiom for complementary services, we can model user choices as

$$P_S(i) = \frac{W_{ij}}{\sum_{(i',j') \in \mathcal{L}} W_{i'j'}}$$

Zero Rating Relationship

- We denote zero rating relationship between CP i and ISP j by θ_{ij}, where θ_{ij}=1 if zero rating relation exists, and θ_{ij}=0 otherwise.
- Θ is an $\mathcal{N}x\mathcal{M}$ matrix



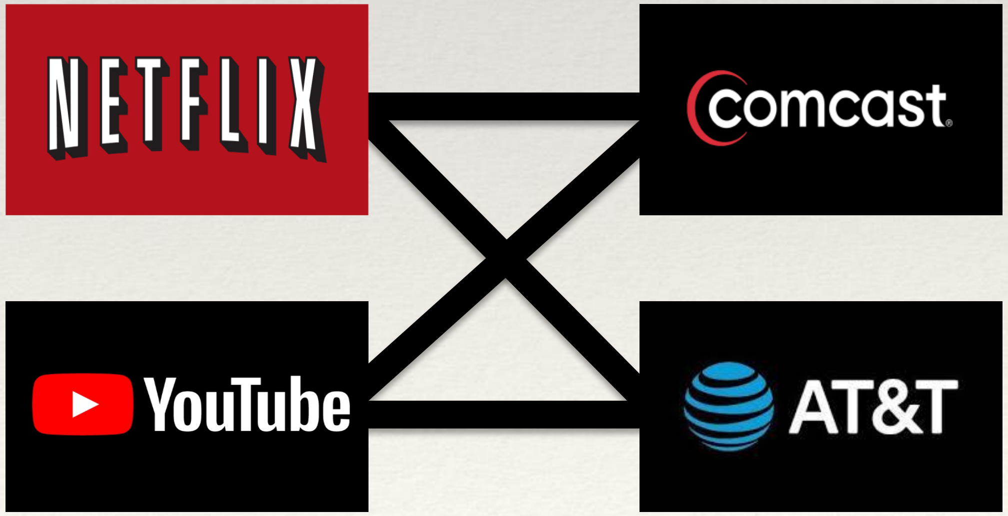
$$\Theta = \begin{pmatrix} 0 & 1 \\ 1 & 1 \end{pmatrix}$$

Market Shares

- Under similar zero rating relationships:
  - Suppose there exist $\mathcal{N}$ CPs and $\mathcal{M}$ ISPs in the market
  - We have dummy CP/ISP to model users who do not utilize any provider
  - Every combination of CPs are considered as an auxiliary CP to model the users who utilize multiple CPs
  - Therefore, in our model we consider $\mathcal{N}' = 2^{\mathcal{N}}$ CPs and $\mathcal{M}' = \mathcal{M}+1$ ISPs

Market Shares (cont'd)

- Each CP $i \in \mathcal{N}'$ has a baseline market share ϕ_i
- Each ISP $j \in \mathcal{M}'$ has a baseline market share ψ_j
- $\sum_{i\in\mathcal{N}'} \boldsymbol{\phi_i} = \sum_{j\in\mathcal{M}'} \boldsymbol{\psi_j} = \mathbf{1}$
- They capture intrinsic characteristics such as price and brand name
- The probability that a user chooses (i,j) under the same zero rating relations is $\phi_i\psi_j$

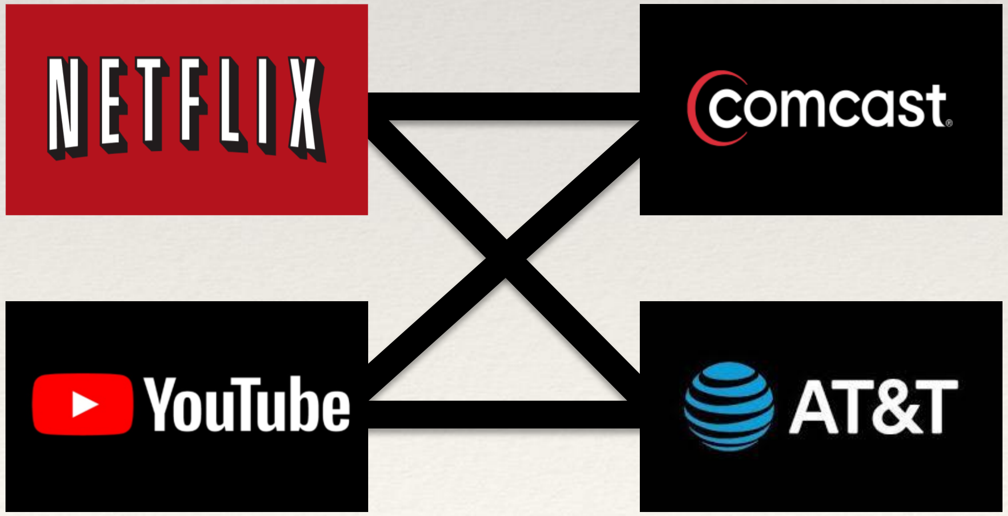


Choices of the users

- Given a nonempty set $\mathcal{L}$ of available choices, a user chooses a choice pair $l = (i,j) \in \mathcal{L}$ with probability:

(Generalized Luce's Choice Axiom)

$$P_{\mathcal{L}}\{l = (i,j)\} = \frac{\phi_i \psi_j}{\sum_{(n,m)\in L} \phi_n \psi_m}$$



Overview

- Both ISPs and CPs decide whether to adopt zero rating
- Consumer surplus impacts users' decisions, and consequently ISP/CP's incomes

Consumer Surplus

- In our model, consumer surplus (CS) for choice pair (i, j) is defined as a constant c_{ij} minus per bandwidth price that consumers pay to CP i, minus per bandwidth price that consumers pay to ISP j

$$CS_{ij} = c_{ij} - q_i - p_j(1- \theta_{ij})$$

in which c_{ij} = a constant in our evaluations.

Stickiness of Users

- Some users stick to CP i or ISP j regardless of other alternative
- Other users seek better alternatives
- Fraction of users sticky to CP i and ISP j are denoted by α_i^0 and β_j^0, respectively
- To capture the impact of CS, we define "effective stickiness" as follows:

$$\alpha_{ij} = \alpha_i^0 \text{ logistic } CS_{ij} \qquad \beta_{ij} = \beta_j^0 \text{ logistic } CS_{ij}$$

Overview

- Both ISPs and CPs decide whether to adopt zero rating
- Consumer surplus impacts users' decisions, and consequently ISP/CP's incomes
- A user model for each pair of ISP-CP is defined, based on the market could reach *zero rating equilibrium*

Choice Model of Users

- Under any zero rating matrix Θ, the number of users (i ,j) can be expressed as:

$$X_{ij}(\Theta, \boldsymbol{\phi}, \boldsymbol{\psi}, \boldsymbol{\alpha}, \boldsymbol{\beta})$$

where

are baseline market share and user stickiness

$$\boldsymbol{\phi} \triangleq (\varphi_1, \dots, \varphi_{\mathcal{N}'}) \qquad \boldsymbol{\psi} \triangleq (\psi_1, \dots, \psi_{\mathcal{M}'})$$

$$\boldsymbol{\alpha} \triangleq (\alpha_1, \dots, \alpha_{\mathcal{N}'}) \qquad \boldsymbol{\beta} \triangleq (\beta_1, \dots, \beta_{\mathcal{M}'})$$

Closed Form Market Shares

THEOREM 3.2. *For a system $(\mathcal{N}, M)$ with a zero rating matrix Θ, the number of users of any pair (i, j) of CP and ISP can be expressed as $X_{ij}(\Theta) = \rho_{ij}(\Theta)\phi_i\psi_j X$, where:*
1) if $\theta_{ij} = 0$,

$$\rho_{ij}(\Theta) = \alpha_{ij}\beta_{ij} + \frac{\boldsymbol{\alpha}_i(\bar{\boldsymbol{\beta}}_i \odot \boldsymbol{\psi})}{\bar{\boldsymbol{\theta}}_i\boldsymbol{\psi}}\mathbf{1}_{\{\boldsymbol{\theta}_i=\mathbf{0}\}} + \frac{\boldsymbol{\beta}^j(\bar{\boldsymbol{\alpha}}^j \odot \boldsymbol{\phi})}{\bar{\boldsymbol{\vartheta}}_j\boldsymbol{\phi}}\mathbf{1}_{\{\boldsymbol{\vartheta}_j=\mathbf{0}\}} + \frac{\boldsymbol{\phi}^T(\bar{\boldsymbol{\alpha}} \odot \bar{\boldsymbol{\beta}})\boldsymbol{\psi}}{\boldsymbol{\phi}^T\bar{\Theta}\boldsymbol{\psi}}\mathbf{1}_{\{\Theta=\mathbf{0}\}}$$

2) if $\theta_{ij} = 1$,

$$\rho_{ij}(\Theta) = \alpha_{ij}\beta_{ij} + \frac{\boldsymbol{\alpha}_i(\bar{\boldsymbol{\beta}}_i \odot \boldsymbol{\psi})}{\boldsymbol{\theta}_i\boldsymbol{\psi}} + \frac{\boldsymbol{\beta}^j(\bar{\boldsymbol{\alpha}}^j \odot \boldsymbol{\phi})}{\boldsymbol{\vartheta}_j\boldsymbol{\phi}} + \frac{\boldsymbol{\phi}^T(\bar{\boldsymbol{\alpha}} \odot \bar{\boldsymbol{\beta}})\boldsymbol{\psi}}{\boldsymbol{\phi}^T\Theta\boldsymbol{\psi}}$$

where $\mathbf{1}_{\{\cdot\}}$ denotes the indicator function, and $\odot$ is the Hadamard (element-wise) product of two matrices.

Utility Model of the Providers

- Revenue of any ISP $j \in \mathcal{M}$:

$$R_j(\Theta) \triangleq \sum_{i \in \mathcal{N}} R_j^i(\Theta)$$

Per user data price of ISP *j*

$$R_j^i(\Theta) \triangleq \begin{cases} p_j X_{ij}(\Theta, \boldsymbol{\phi}, \boldsymbol{\psi}, \boldsymbol{\alpha}, \boldsymbol{\beta}), & if \quad \theta_{ij} = 0 \\ \delta_j p_j X_{ij}(\Theta, \boldsymbol{\phi}, \boldsymbol{\psi}, \boldsymbol{\alpha}, \boldsymbol{\beta}), & if \quad \theta_{ij} = 1 \end{cases}$$

data discount of ISP *j to CPs*

- Profit of any CP $i \in \mathcal{N}$:

$$U_i(\Theta) \triangleq \sum_{j \in \mathcal{M}} U_i^j(\Theta)$$

Per user value of CP *i*

$$U_i^j(\Theta) \triangleq \begin{cases} q_i X_{ij}(\Theta, \boldsymbol{\phi}, \boldsymbol{\psi}, \boldsymbol{\alpha}, \boldsymbol{\beta}), & if \quad \theta_{ij} = 0 \\ (q_i - \delta_j p_j) X_{ij}(\Theta, \boldsymbol{\phi}, \boldsymbol{\psi}, \boldsymbol{\alpha}, \boldsymbol{\beta}), & if \quad \theta_{ij} = 1 \end{cases}$$

Zero Rating Equilibrium

- In a market of ISPs and CPs, given a fixed discount and price profiles, a zero rating strategy profile is a *zero rating equilibrium* (ZRE) if and only if 1) given a zero rating strategy Θ chosen by ISPs, neither of CPs would gain by unilaterally deviating from it 2) given a zero rating strategy Θ chosen by CPs, neither of ISPs would gain by unilaterally deviating from it.

- If Θ is a zero rating equilibrium

$$\forall i \in \mathcal{M}: \quad U_i(\boldsymbol{\Theta}) \geq U_i\left(\bar{\theta}_{ij}; \boldsymbol{\Theta}_{-ij}\right)$$

$$\forall j \in \mathcal{N}: \quad R_j(\boldsymbol{\Theta}) \geq R_j(\bar{\theta}_{ij}; \boldsymbol{\Theta}_{-ij})$$

Overview

- Both ISPs and CPs decide whether to adopt zero rating
- Consumer surplus impacts users’ decisions, and consequently ISP/CP’s incomes
- A user model for each pair of ISP-CP is defined, based on which the market could reach *zero rating equilibrium*
- CPs might make decisions under zero rating pressure

Zero Rating Pressure

- Sometimes a CP only chooses to establish ZR because its competitor does; otherwise it does not gain by establishing the ZR
- Resembles peering pressure
- Usually causes low-value CP to have utility loss, whereas it’s not necessarily true for high-value CP
- The case where both CPs lose utility is similar to prisoner’s dilemma

Overview

- Both ISPs and CPs decide whether to adopt zero rating
- Consumer surplus impacts users' decisions, and consequently ISP/CP's incomes
- A user model for each pair of ISP-CP is defined, based on which the market could reach *zero rating equilibrium*
- CPs might make decisions under zero rating pressure
- We numerically analyze the decisions and consequent incomes of ISPs/CPs in duopolistic market of providers

Monopolistic ISP

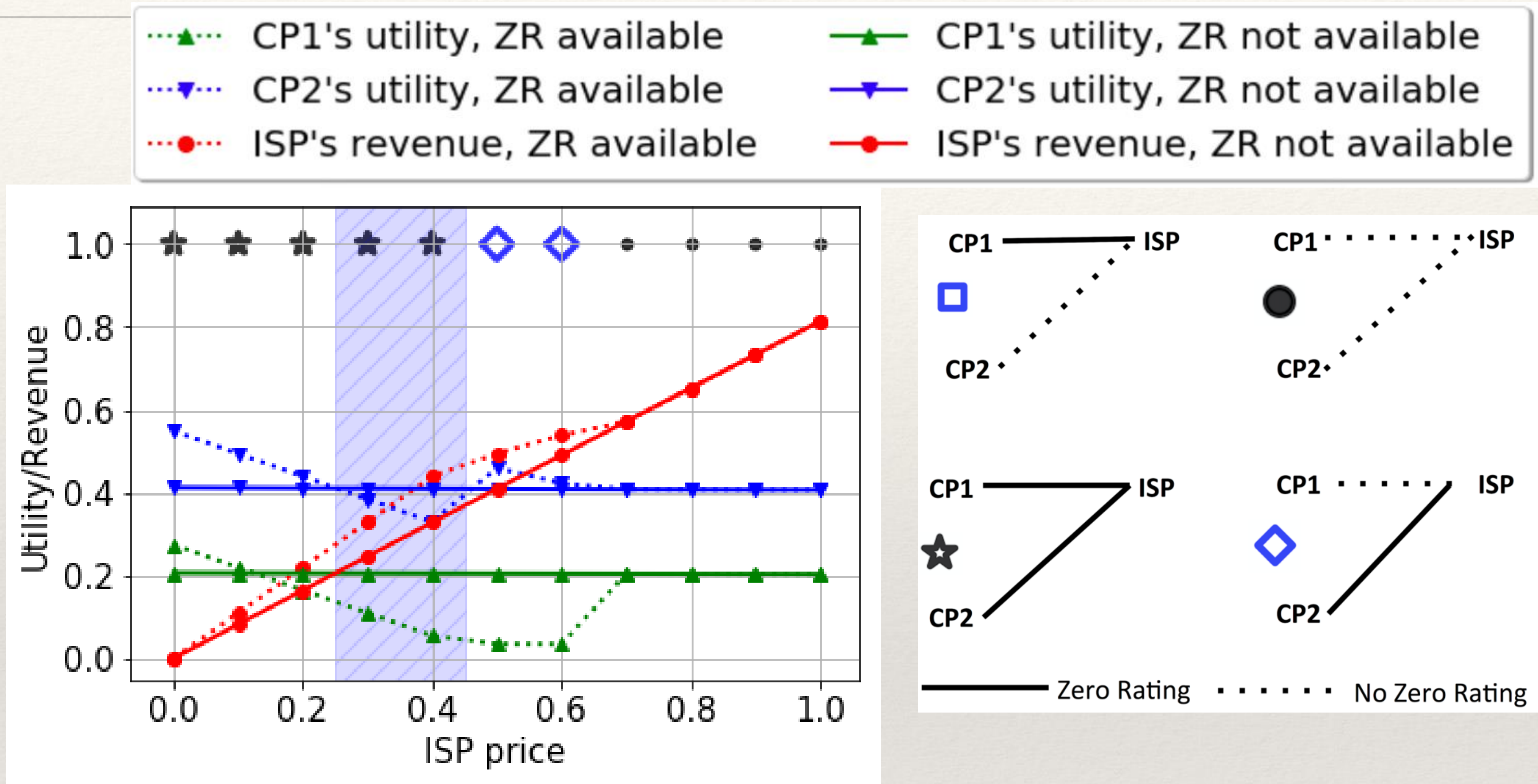
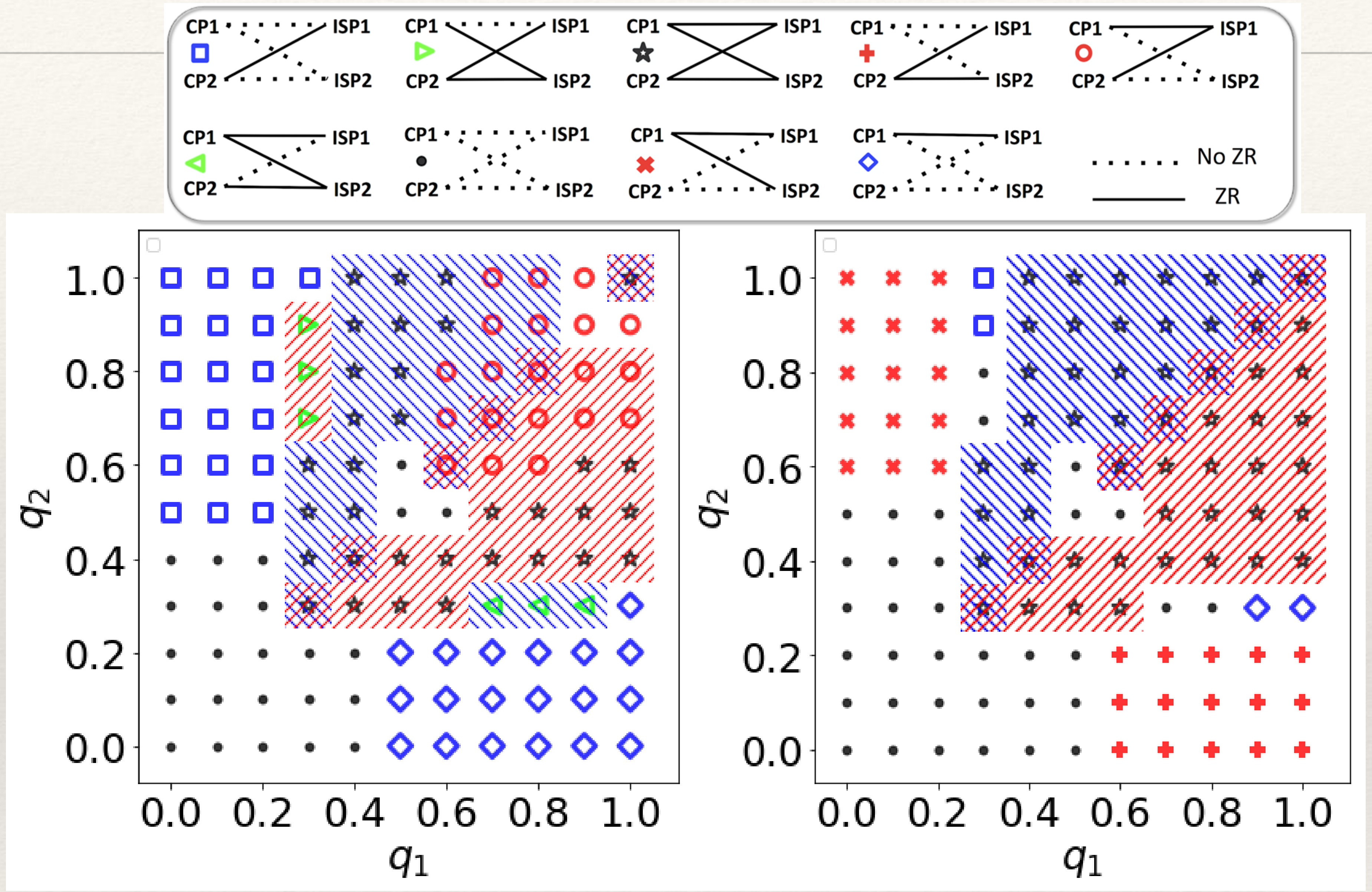


Figure 1: zero rating equilibria and revenue graphs in the monopolistic ISP market with $\boldsymbol{\phi} = (0.4, 0.4, 0.1, 0.1)$, $\boldsymbol{\psi} = (0.8, 0.2)$, $\boldsymbol{\alpha}^0 = (0.5, 0.5)$, $\boldsymbol{\beta}^0 = (0.5)$, **and** $\boldsymbol{q} = (0.5, 1.0)$. ϕ_3 and ϕ_4 are dummy CP's and CP1CP2's market share, respectively, and ψ_2 is dummy ISP's market share. The dashed lines depict the cases where zero rating (ZR) is allowed and a zero rating equilibrium exists. The solid lines depict the case where no zero rating relation is allowed in the market.

Complementary Duopoly



(a) $\boldsymbol{p}$ = (0.5, 1.0) (b) $\boldsymbol{p}$ = (0.5, 0.5)

Figure 2: zero rating equilibria under complementary duopoly with $\boldsymbol{\alpha}^0 = \boldsymbol{\beta}^0 = (0.8, 0.8)$, $\boldsymbol{\phi} = (0.4, 0.4, 0.1, 0.1)$, $\boldsymbol{\psi} = (0.4, 0.4, 0.2)$. Shaded areas in blue (\) and red (/) represent zero rating pressure for CP 1 and CP 2, respectively.

Herfindahl index

- to show the impact of zero rating on the market and user welfare, we have utilized **Herfindahl index**.
  - sum of squares over the market shares of all firms in the market.
  - When grows to 1, the market moves from a collaborative state to a monopolistic content provider, i.e., the competition decreases.
  - Lack of competition causes market distortion and welfare loss due to monopoly.

Herfindahl index (cont'd)

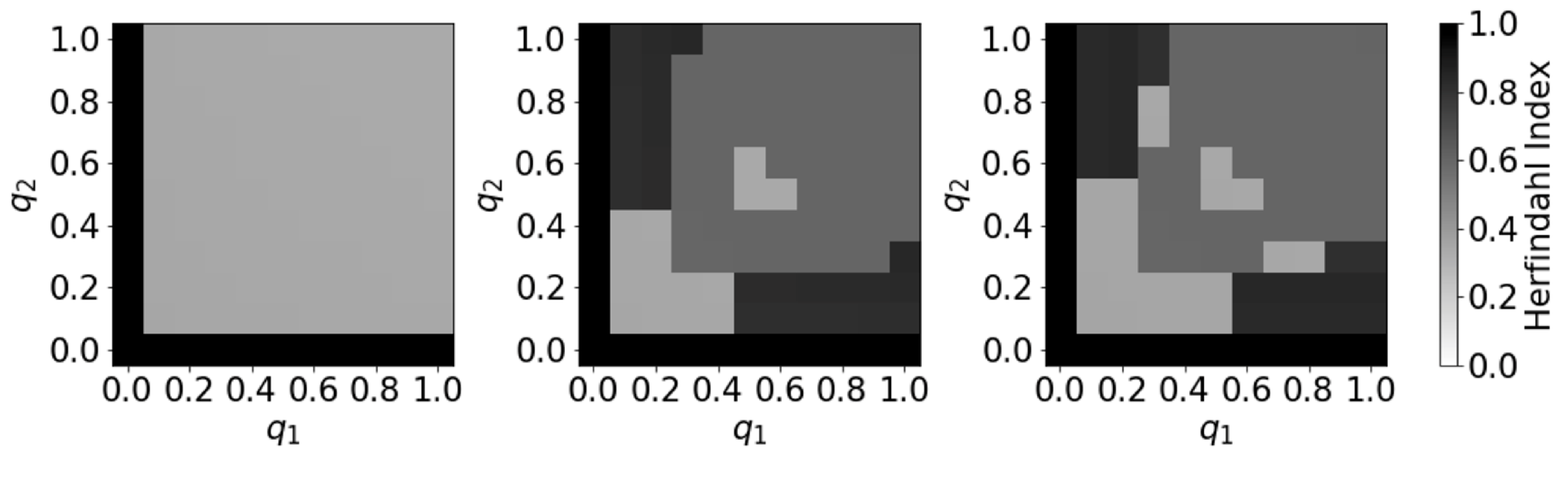


Figure 3: The Herfindahl index (shown by HHI) for the market of CPs when (a) zero rating (ZR) is not available (b) zero rating is available and ***p*** = (0.5, 0.5) (c) zero rating is available and ***p*** = (0.5, 0.5). The parameters and resulting equilibria can be found in Figure 2.

Conclusions

- If zero rating options are allowed in the market, low-value CPs usually have utility loss, whereas high value CPs usually have utility gains
- With zero rating options allowed in the market, the Herfindahl index will never increase which implies the competition of the system decreases
- Our finding supports the notion that differential pricing is not consistent with Network Neutrality
- zero rating typically disadvantages low-value CPs and could have a stunting impact on innovations.

(Re)Defining Network Neutrality

The Internet should provide a platform that does not provide a competitive advantage to specific content/app/services, either through pricing or quality of service

Post Differential Pricing Ruling in India: 3 years out

- Internet penetration has accelerated
- Broadband speeds have improved
- India has the cheapest data prices anywhere in the world
  - A large part is due to the disruptive entry of Jio
  - Ex-ante differential pricing ruling meant Jio offered free data for **all** of Internet, and competitors followed suit
  - OTT providers like Netflix, Amazon Prime, Hotstar grew exponentially in usage and content

Thought experiment: world without Differential Pricing Regulations

- Jio offers free data for Jio Movies, Jio TV, Jio Music
- Airtel offers free data for the Airtel versions
- OTT providers not offered by ISPs would have stunted growth
  - Possibly sign zero-rating deals with a subset of ISPs
  - Balkanized, confusing marketplace..

Questions?