Game Theoretical Analysis of Resource Allocation in the InterPlanetary File System

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Background

IPFS (InterPlanetery File System)

- P2P hypermedia distribution protocol
  - **Goal:** Replace HTTP, decentralize Internet
- Content-addressed, versioned filesystem
- Git repo in a torrent

IPFS Stack

Figure 1: The IPFS Stack

Bitswap

- IPFS's block exchange protocol
- Inspired by BitTorrent
- *Given a set of peers who want data, how to allocate resources?*

Bitswap

Given a set of peers who want data, how to allocate resources?

- Ever user maintains reputation for each peer
  - Very complex dynamics
- **Reciprocation function**

Objectives

- Discover Bitswap reciprocation function(s) that gives desired behavior
  - Will depend on conditions
  - Break down Bitswap dynamics
- Analytical and empirical analyses
- Implementation

System Model

IPFS Network as Graph

- *Nodes*: Users $\in \mathcal{N}$
- *Edges*: Peerings; unweighted, undirected
  - i's *neighborhood*: $\mathcal{N}_i \subseteq \mathcal{N}$

Reputation

User i distributes B_i bits among peers in each round

- b_{ji}^t: Total bits sent from user j to peer i from round 0 to $t-1$
- d_{ji}^t: *debt ratio* of j as viewed by i in round t
  - Used as peer-wise reputation

$$d_{ji}^t = \frac{b_{ji}^t}{b_{ij}^t}$$

Reciprocation Function

- *Inputs*: Peer debt ratio, rest of peers' debt ratios
- *Output*: Peer weight
- $S_j(d_{ji}^t, \mathbf{d}_j^{-i,t}) \in [0,1]$
  - e.g. $S_j(d_{ji}^t, \mathbf{d}_j^{-i,t}) = \frac{d_{ji}^t}{d_{ji}^t + \sum_{d_{jk}^t \in \mathbf{d}_j^{-i,t}} d_{jk}^t}$

Data Distribution

B_j bits distributed among peers via weighted round-robin

$$b_{ji}^{t+1} = b_{ji}^{t} + S_j(d_{ji}^{t}, \mathbf{d}_j^{-i,t}) \times B_j$$

Game Formulation

- *Players*: Users/nodes
- *Strategy*: Reciprocation function
- *Utility*: $U_i = \sum_{j \in \mathcal{N}_i} b_{ji}^{\infty} = \sum_{t=0}^{\infty} u_i^t$

$$u_i^t = \sum_{t=0}^{\infty} \sum_{j \in \mathcal{N}_i} (b_{ji}^t - b_{ji}^{t-1})$$

Model Iterations

- *Complexity* vs. *accuracy*
- Attempted formulations
  - Evolutionary game theory
  - Statistical mechanics
  - **Repeated games**

Game Characteristics

- *Infinitely repeated*
  - Discrete rounds, denoted by t
- *Incomplete information*

Objectives

- Classify Bitswap reciprocation functions
  - Conditions where useful
- **Analytical work:** Repeated game model
- **Empirical work:** Simulations
- **Implementation:** `go-ipfs`, IPTB

Preliminary Results

Strategy Simulator

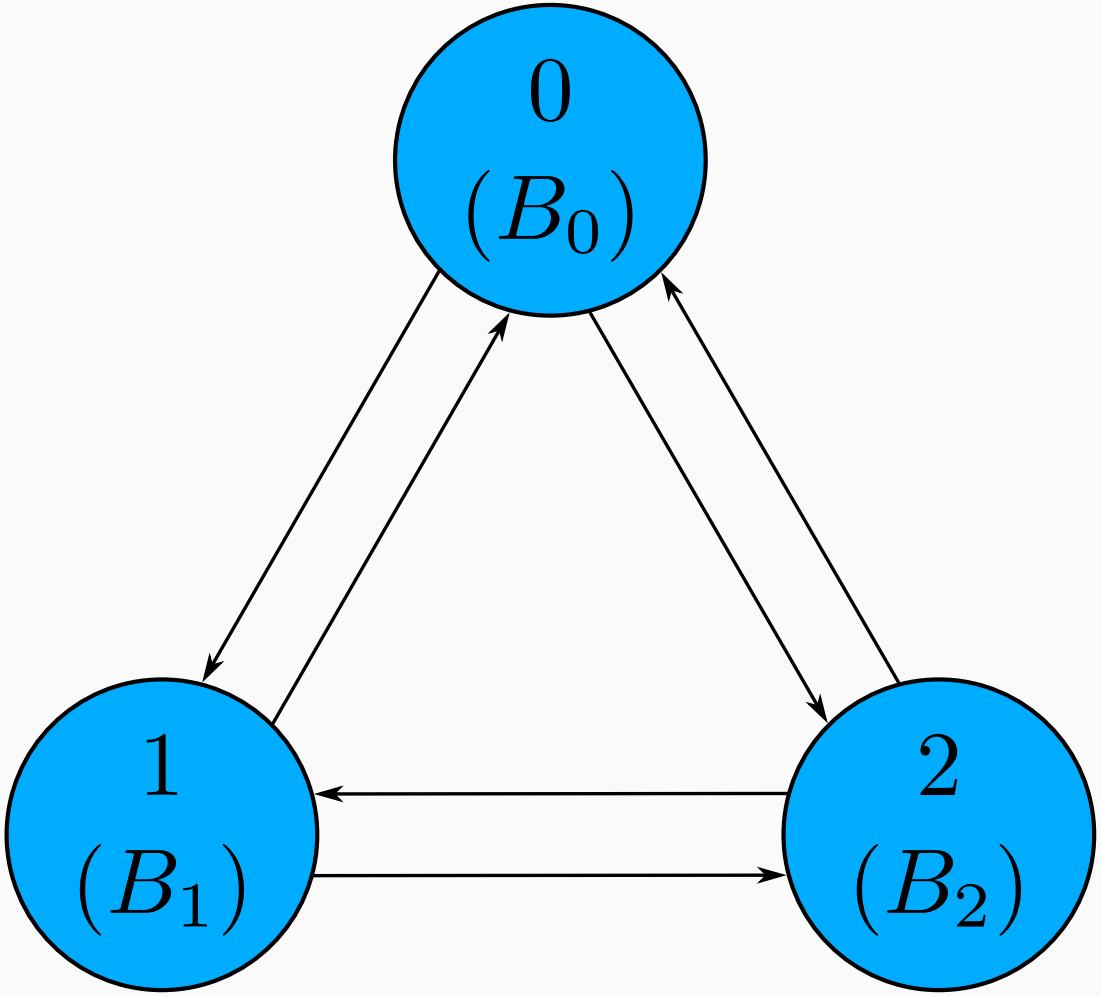
- 3 node network
- Parameters
  - Resource distribution
  - Initial peer-wise reputations
- Tests whether given reciprocation function is a Nash equilibrium (NE)

Strategy Simulator

User 0:

1. Follows reciprocation function
2. Deviates from reciprocation function

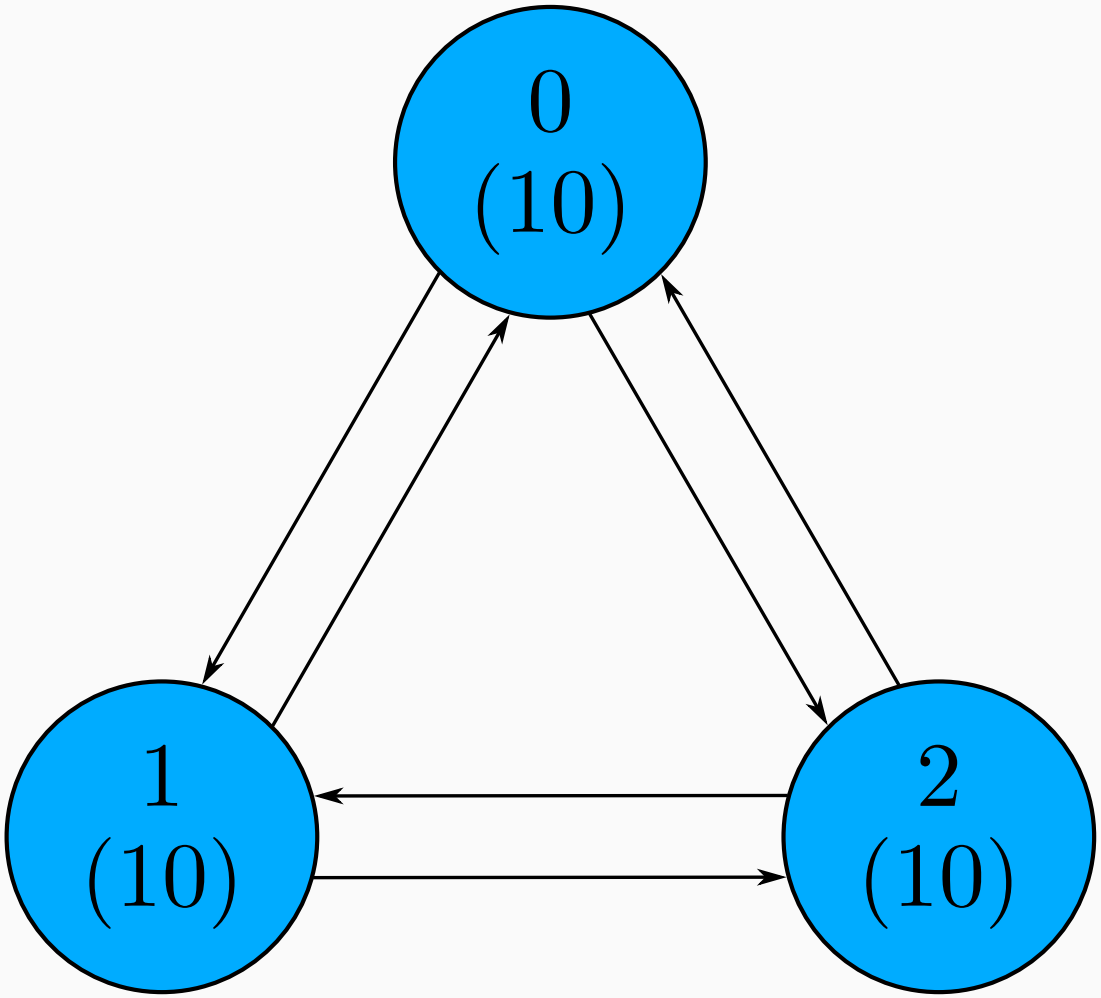
3-Node Network



Example 1

- **Reciprocation function:** Linear
- **Initial ledgers:** Split
- **Resource distribution:** $[10, 10, 10]$

Example 1 – Non-Deviating



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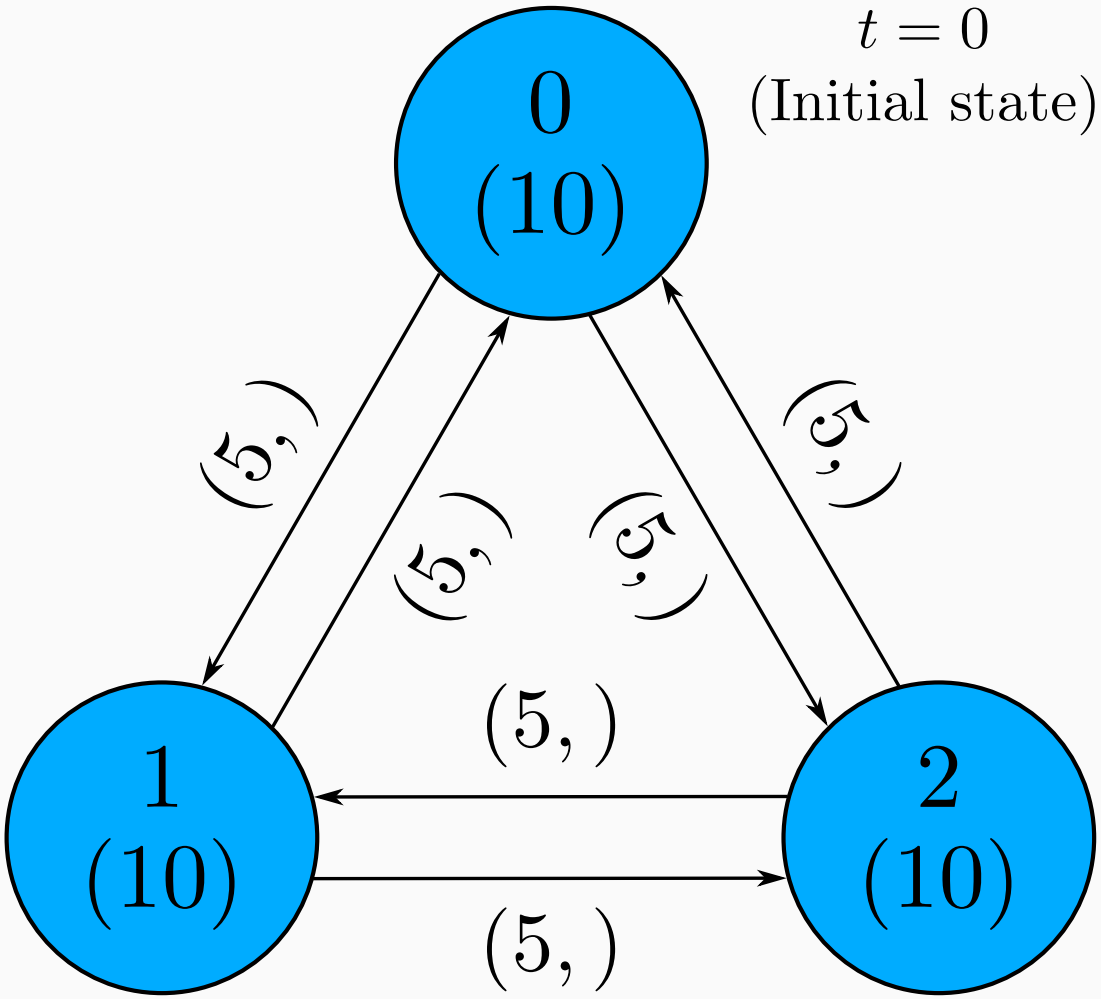

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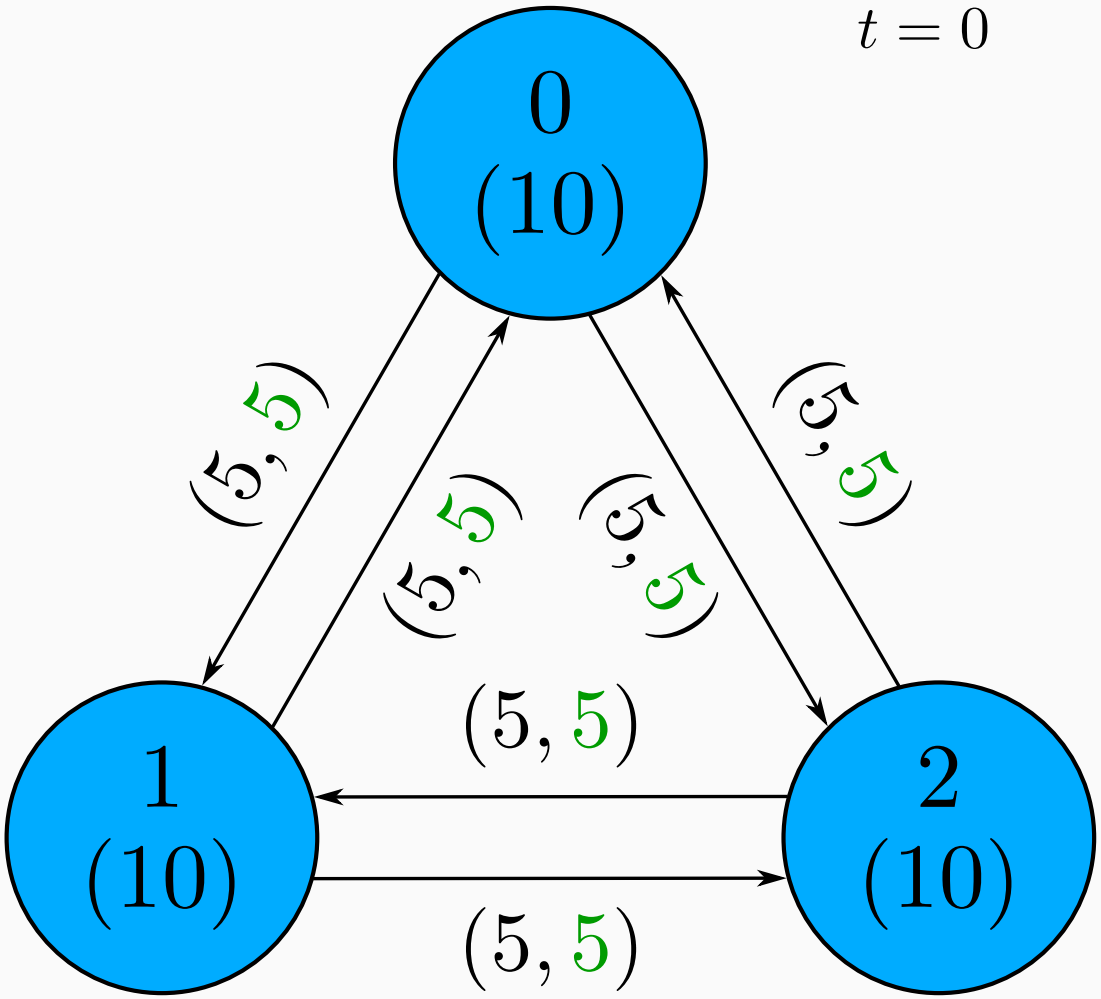

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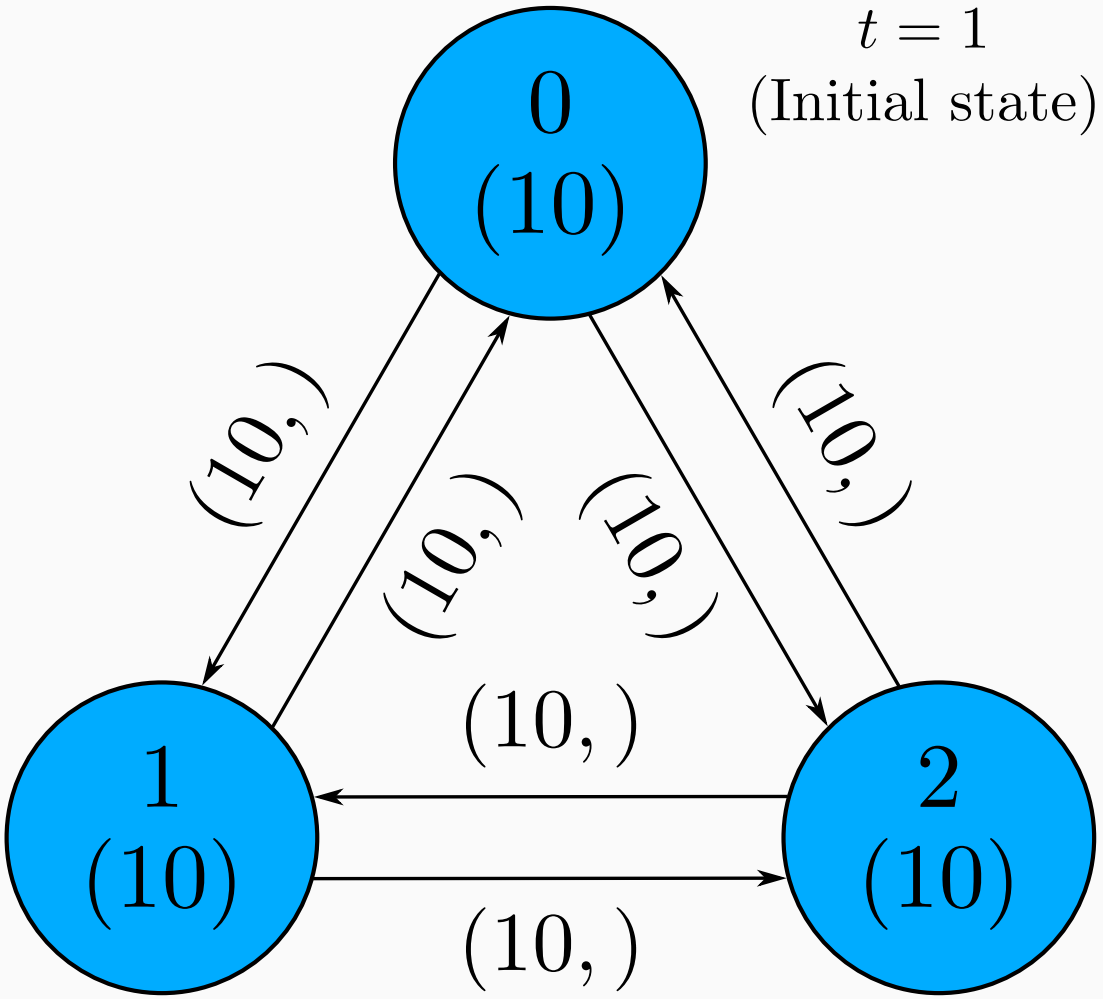

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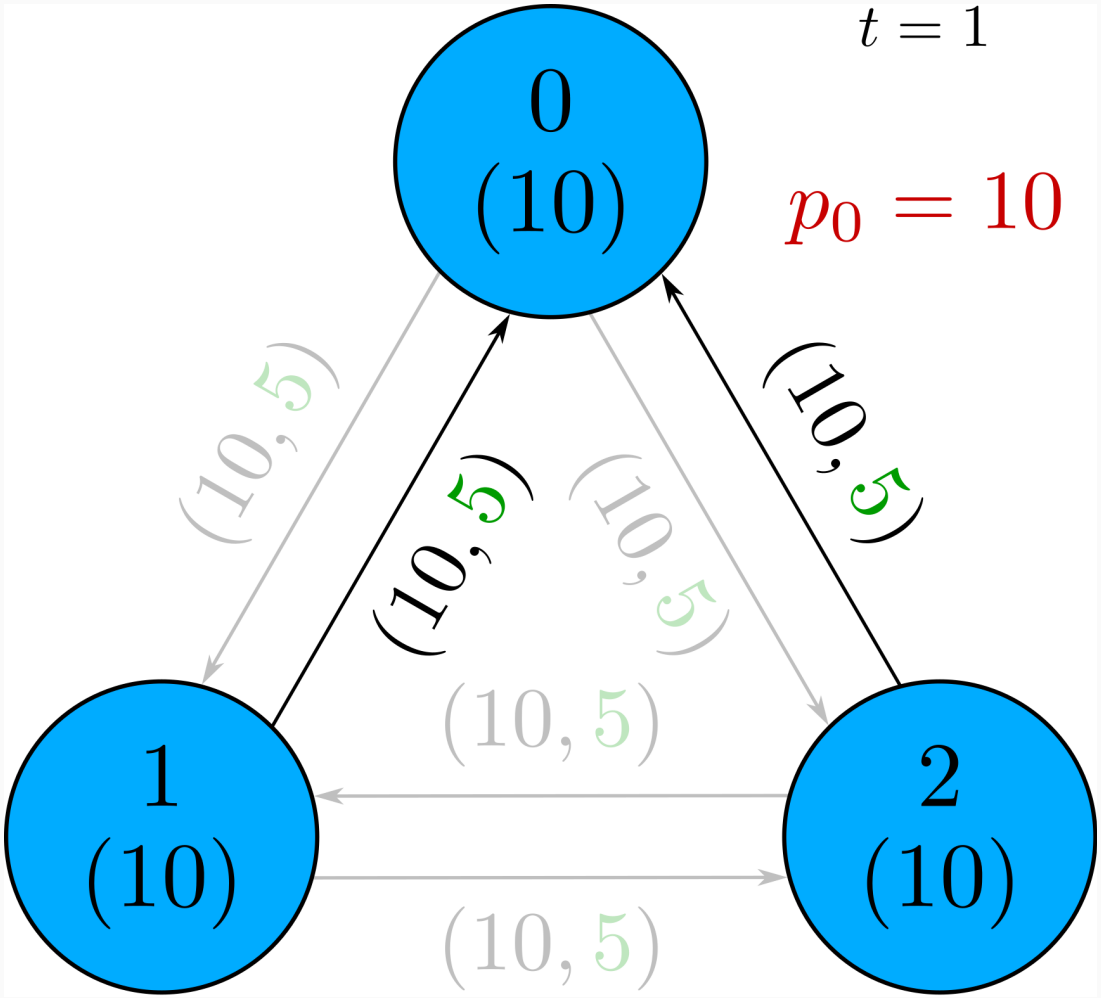

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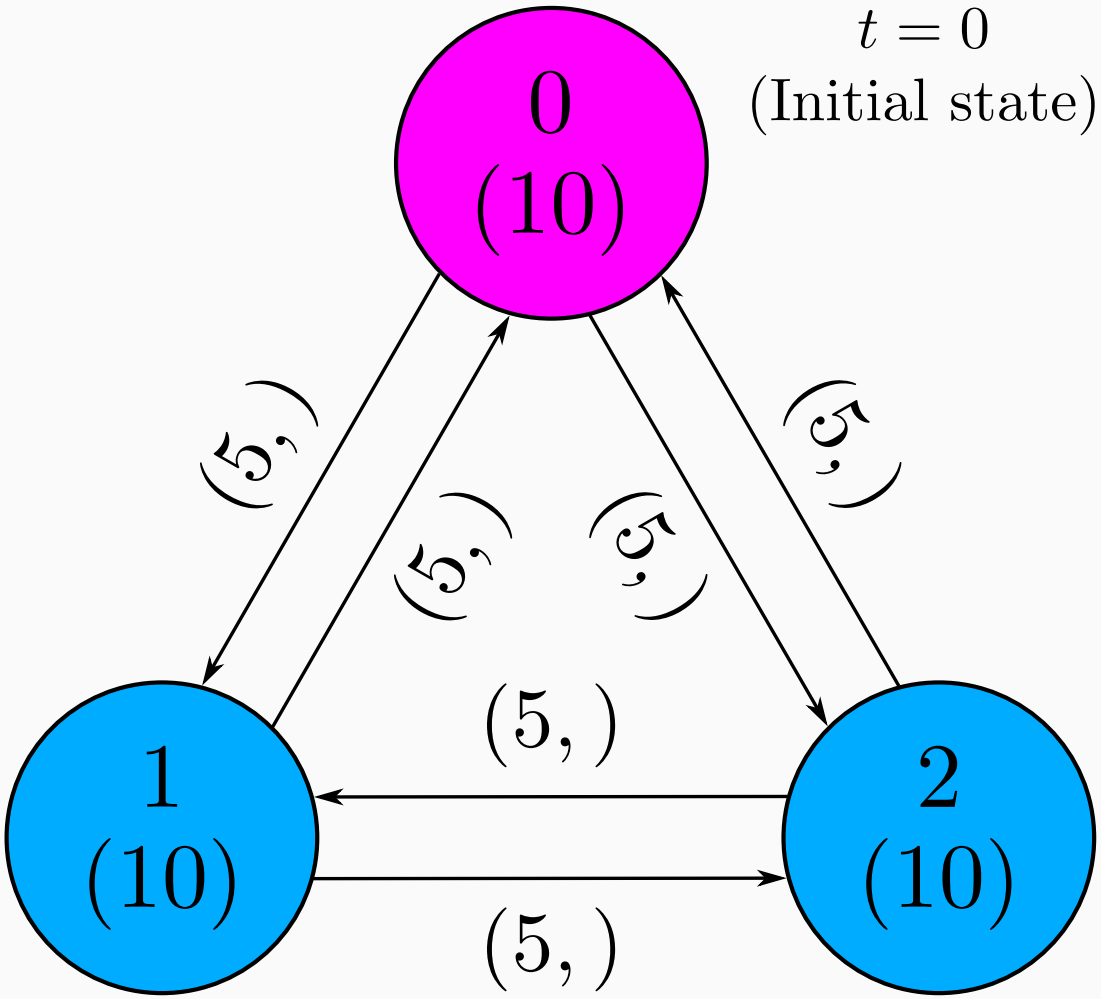

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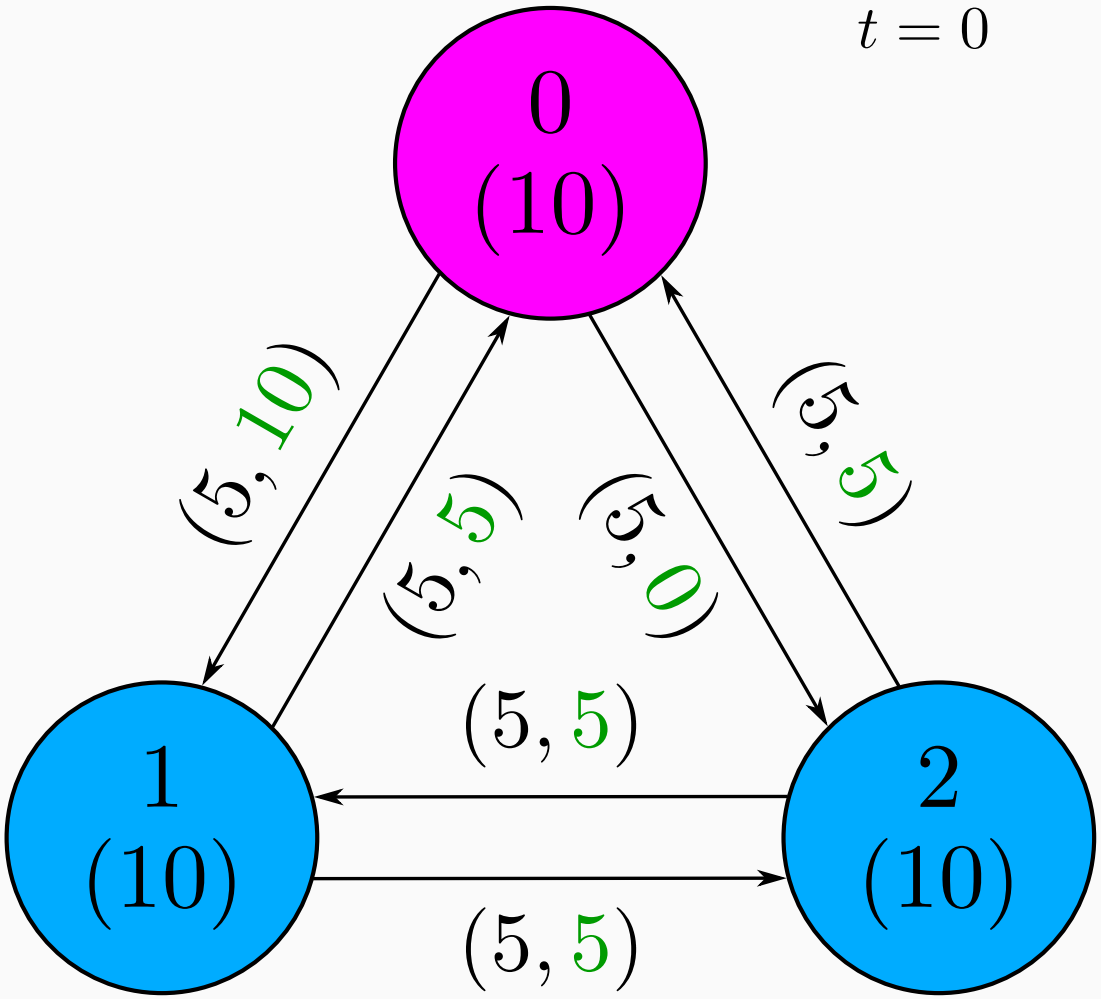

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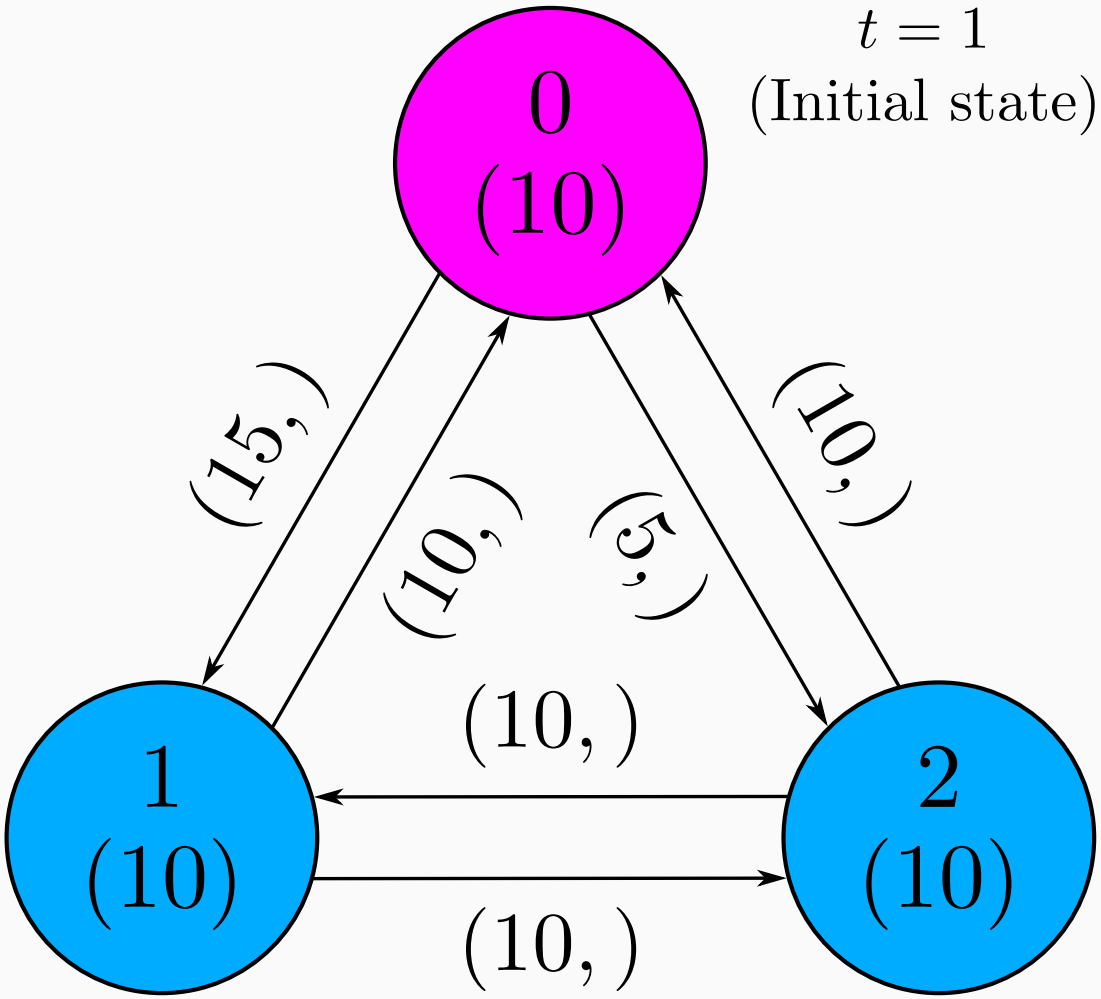

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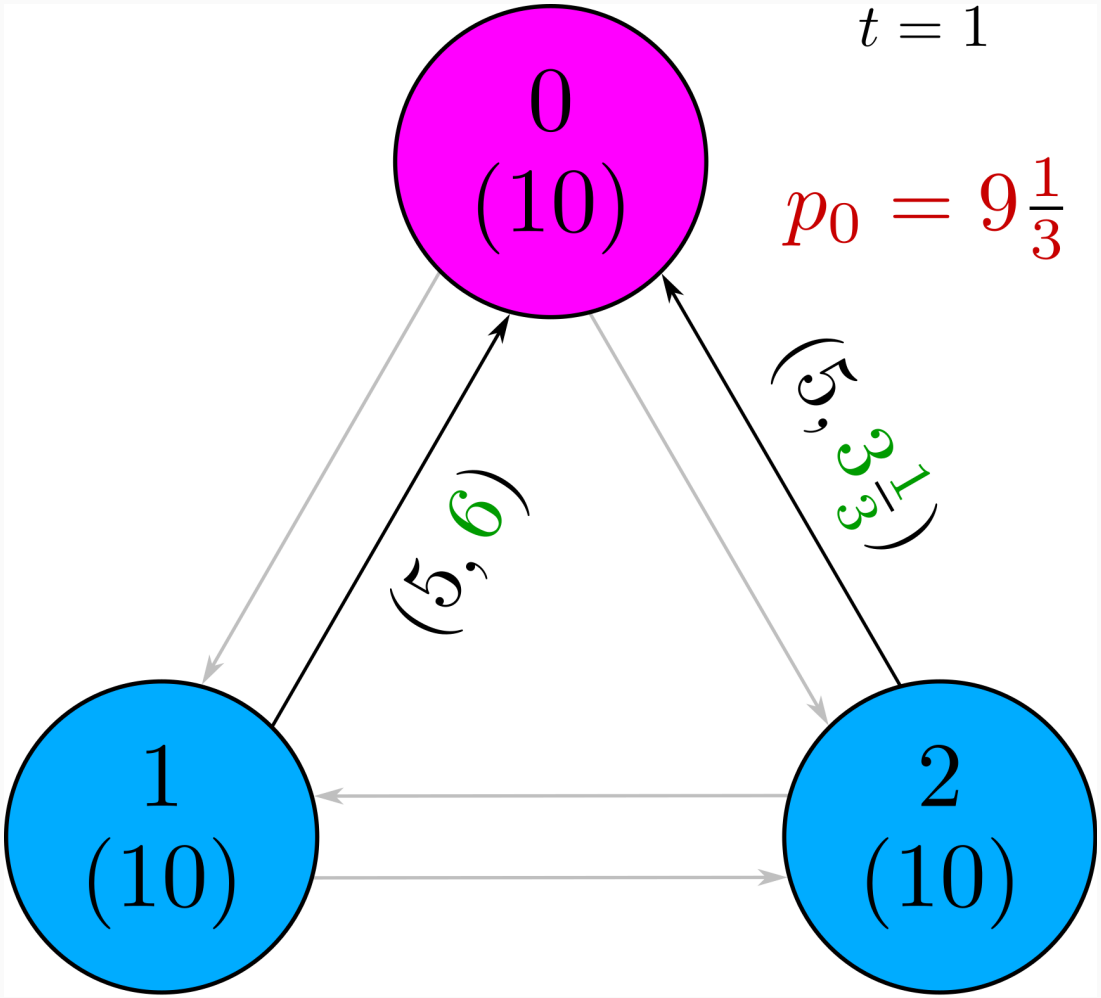
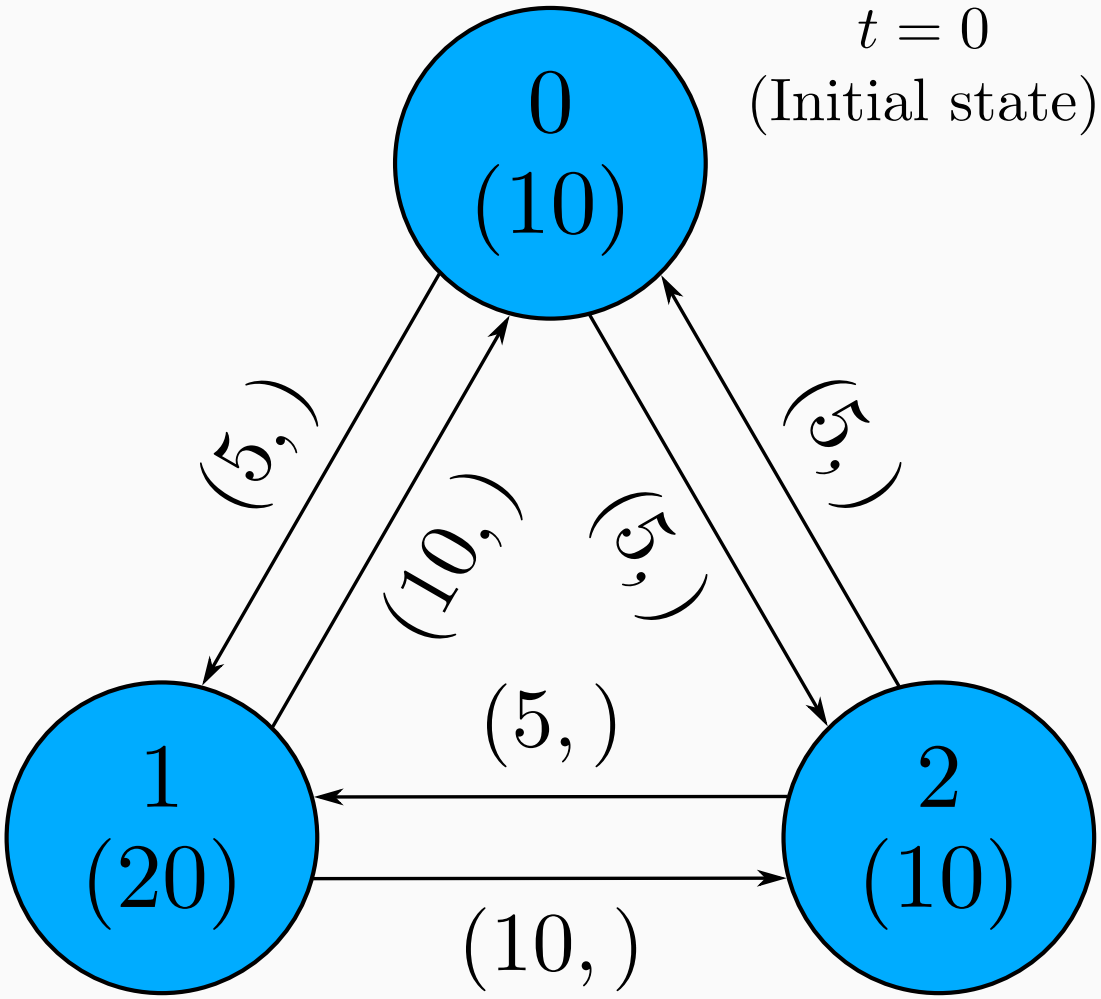


Example 2

- **Reciprocation function:** Linear
- **Initial ledgers:** Split
- **Resource distribution:** $[10, 20, 10]$

Example 2 – Non-Deviating



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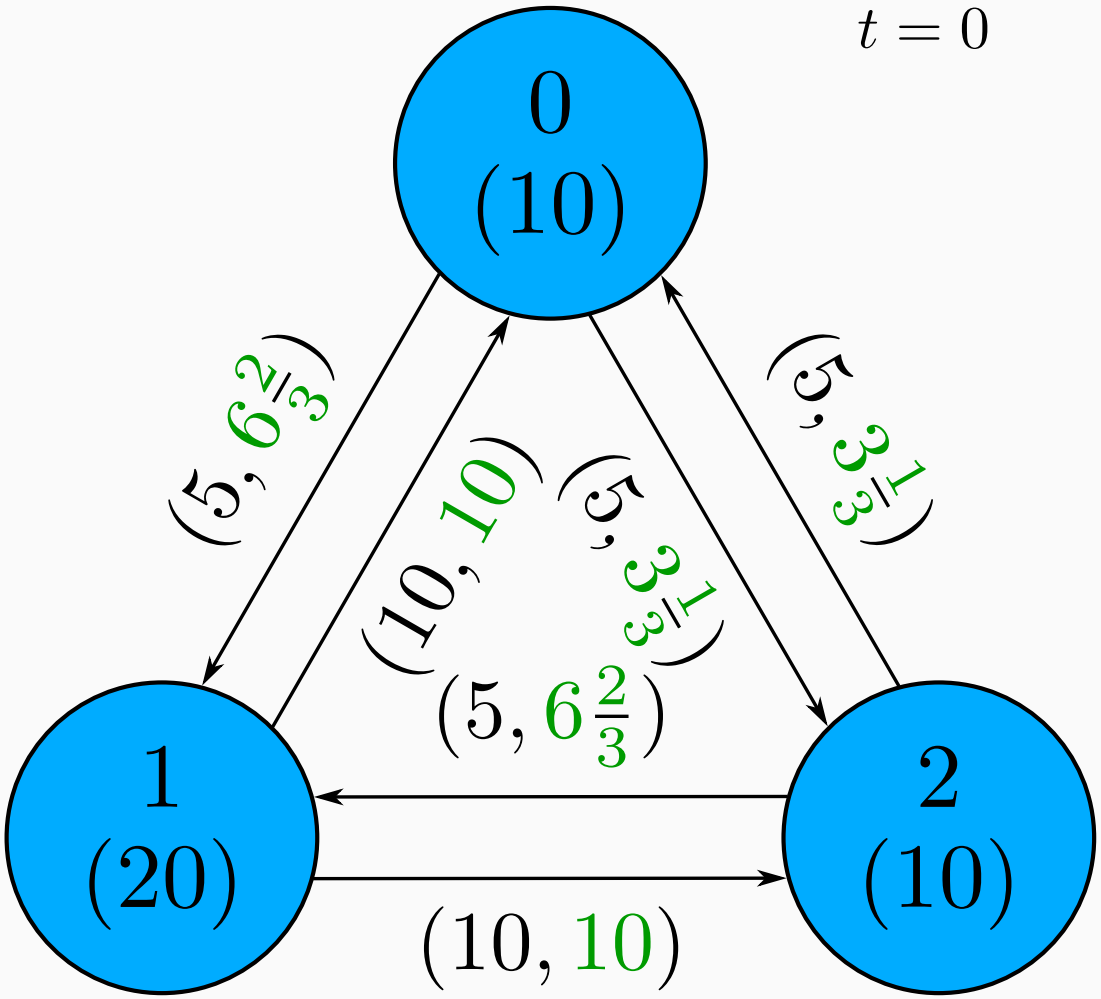

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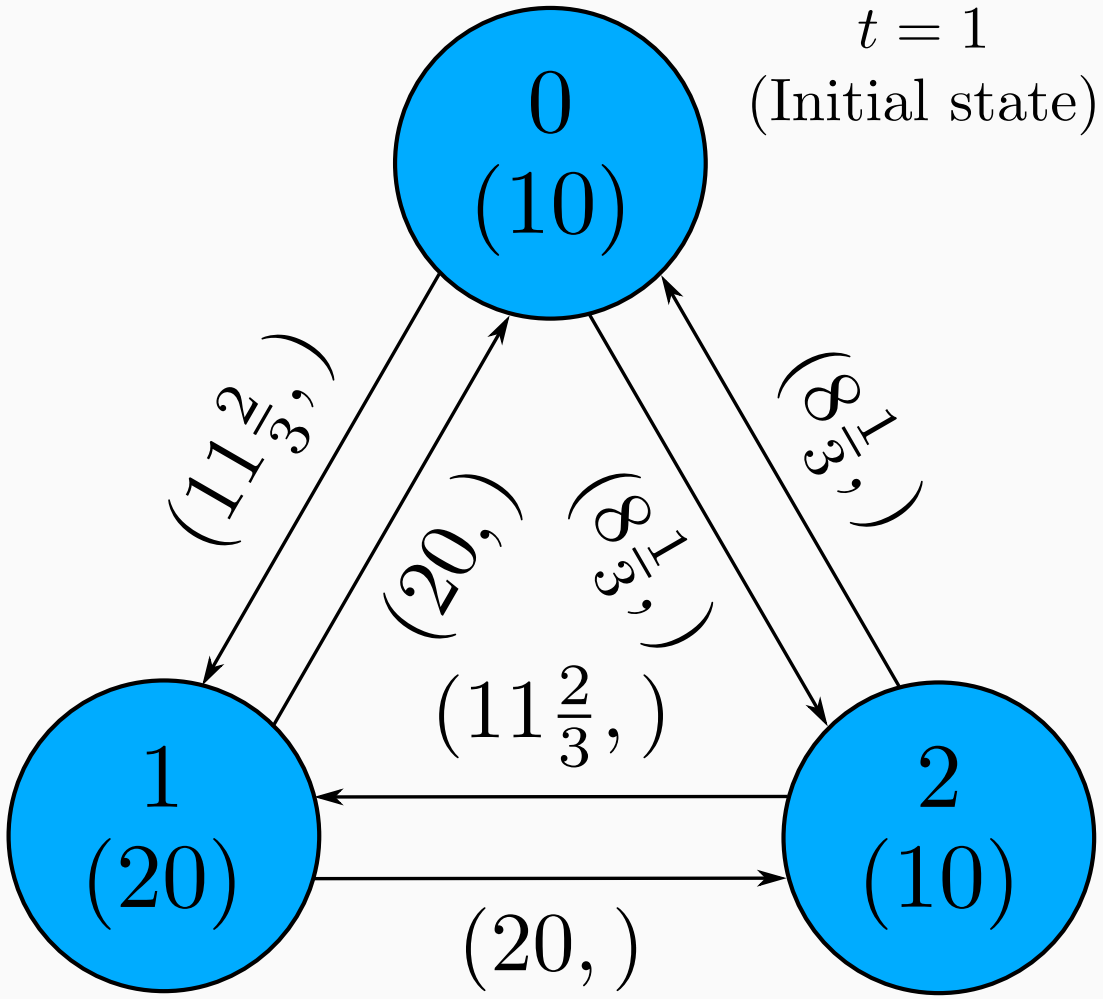

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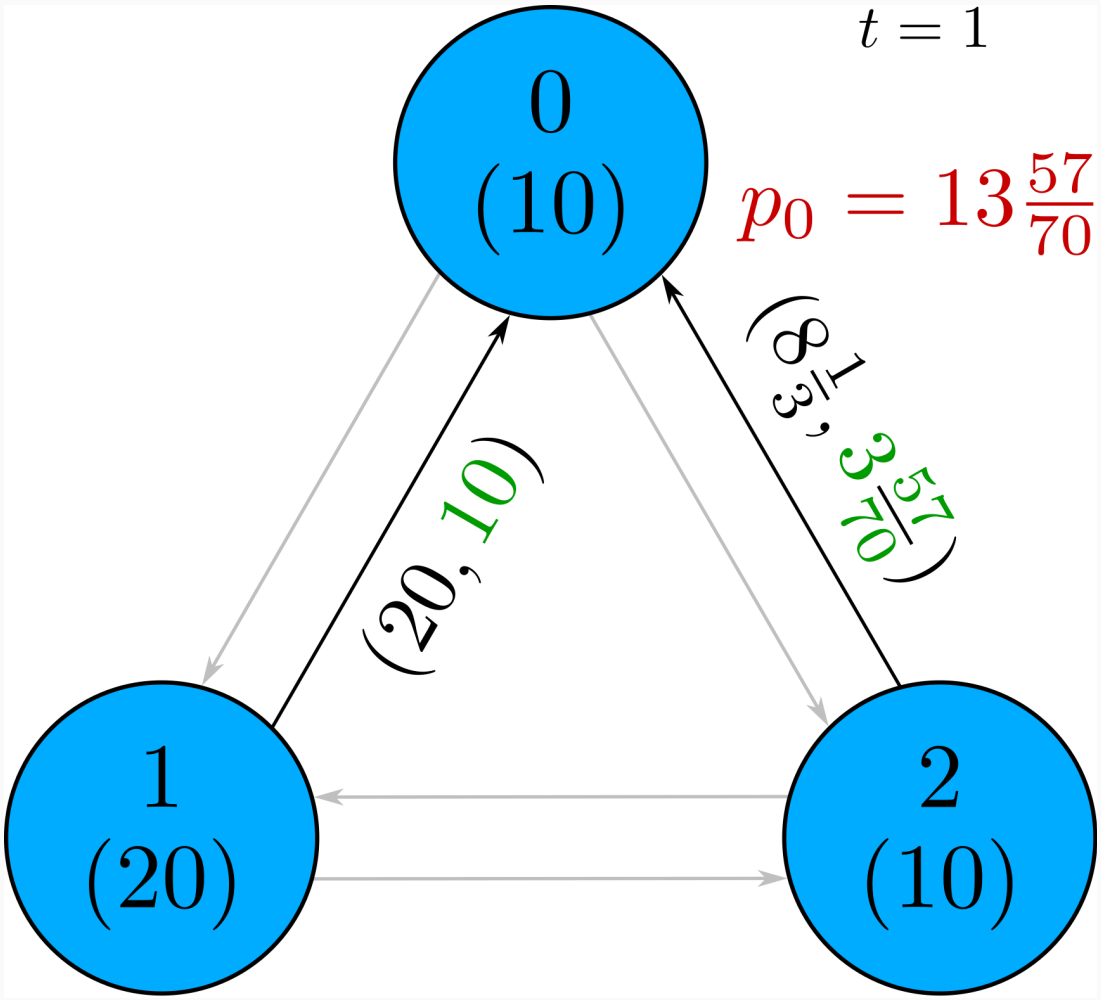

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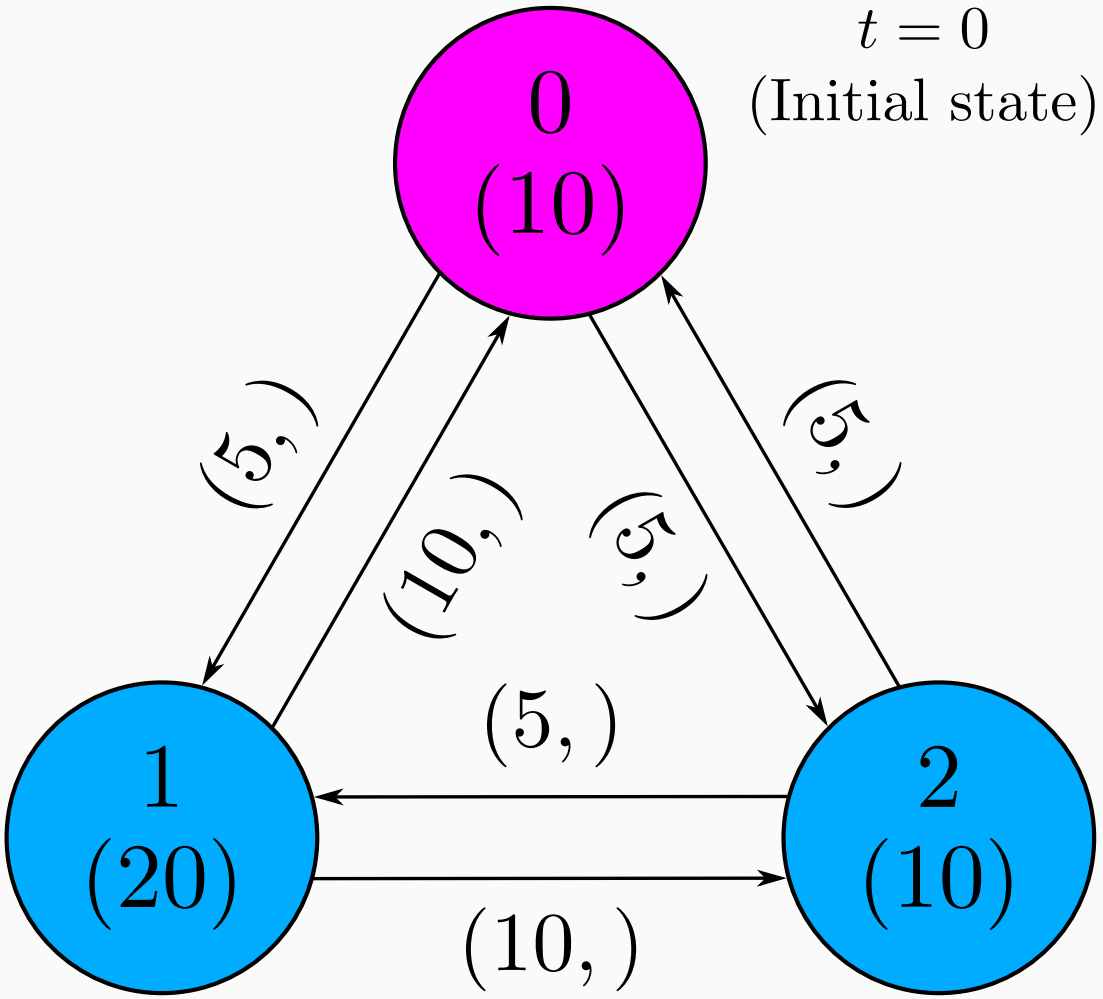

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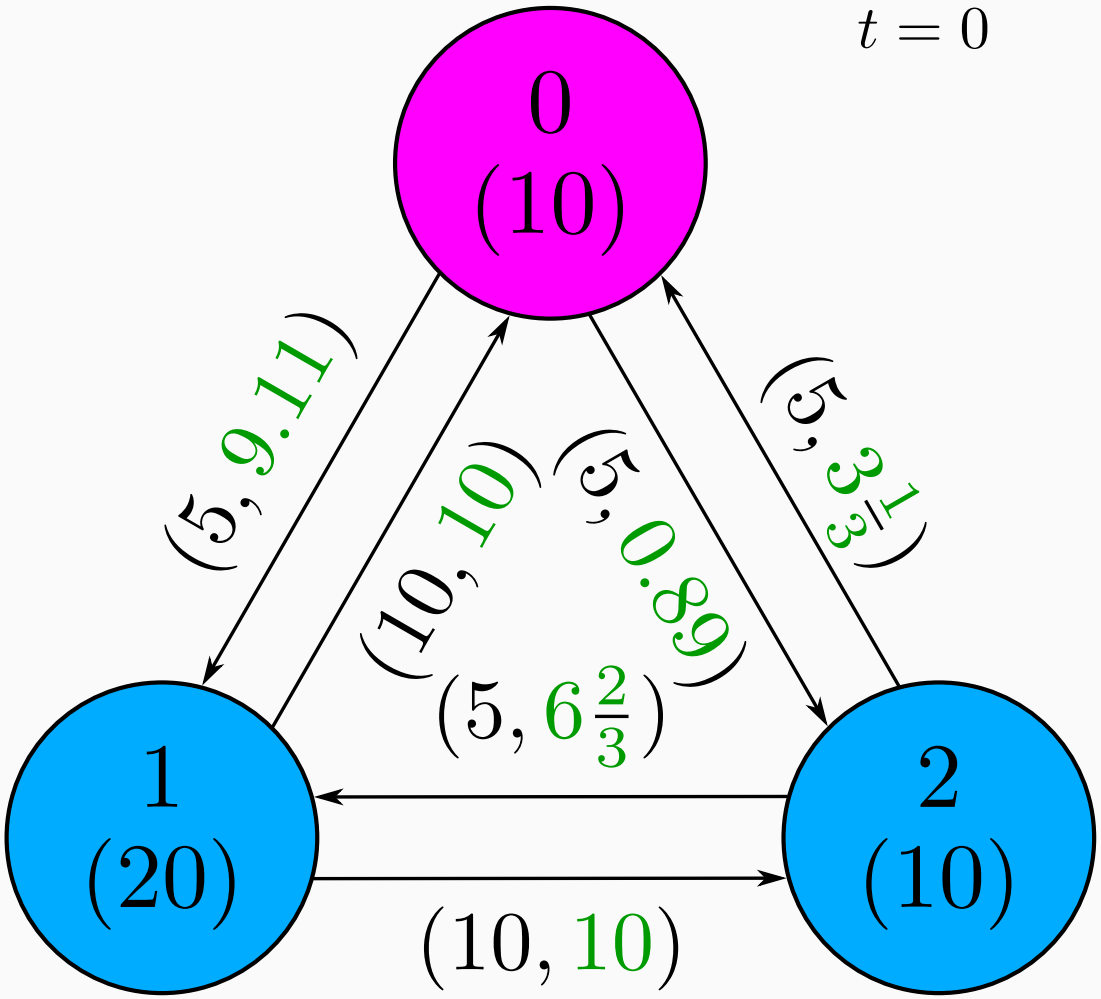

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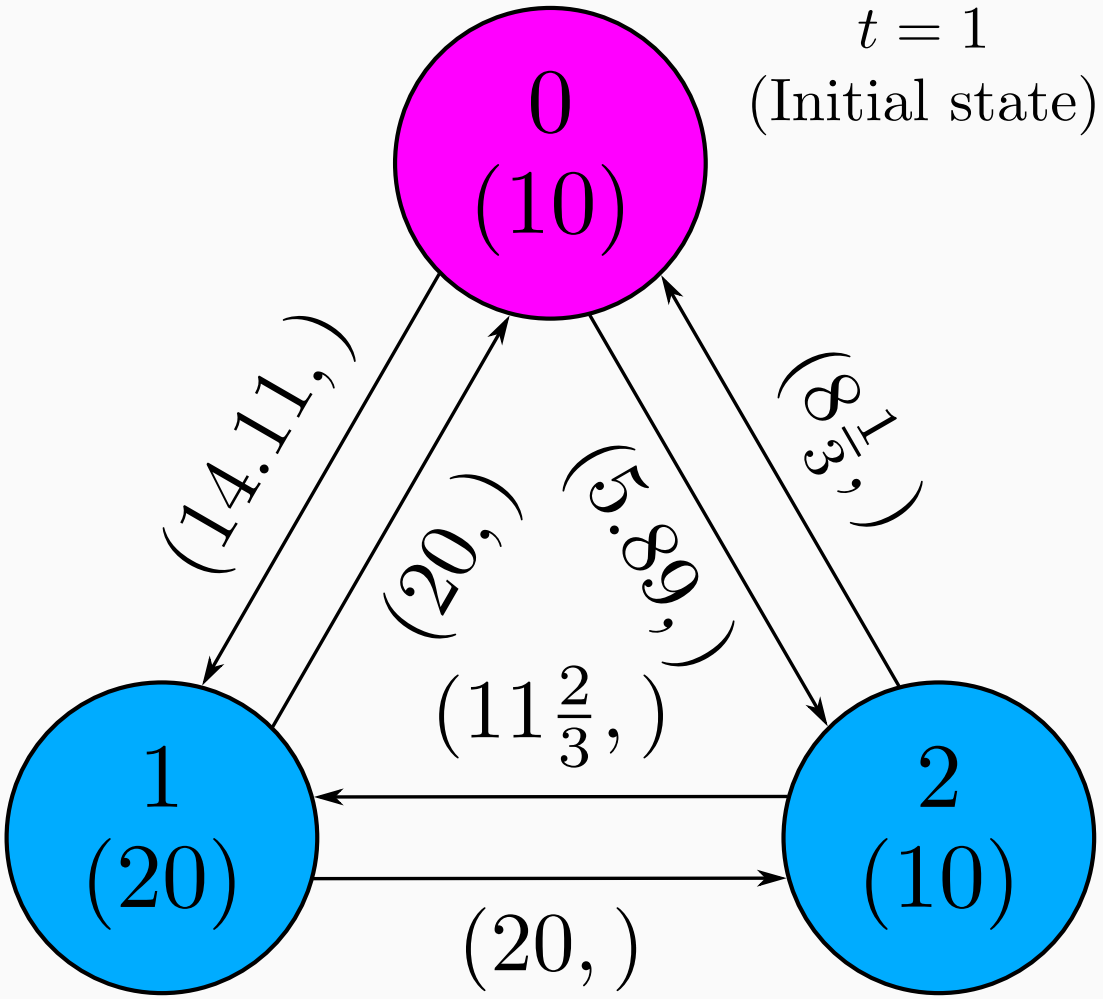

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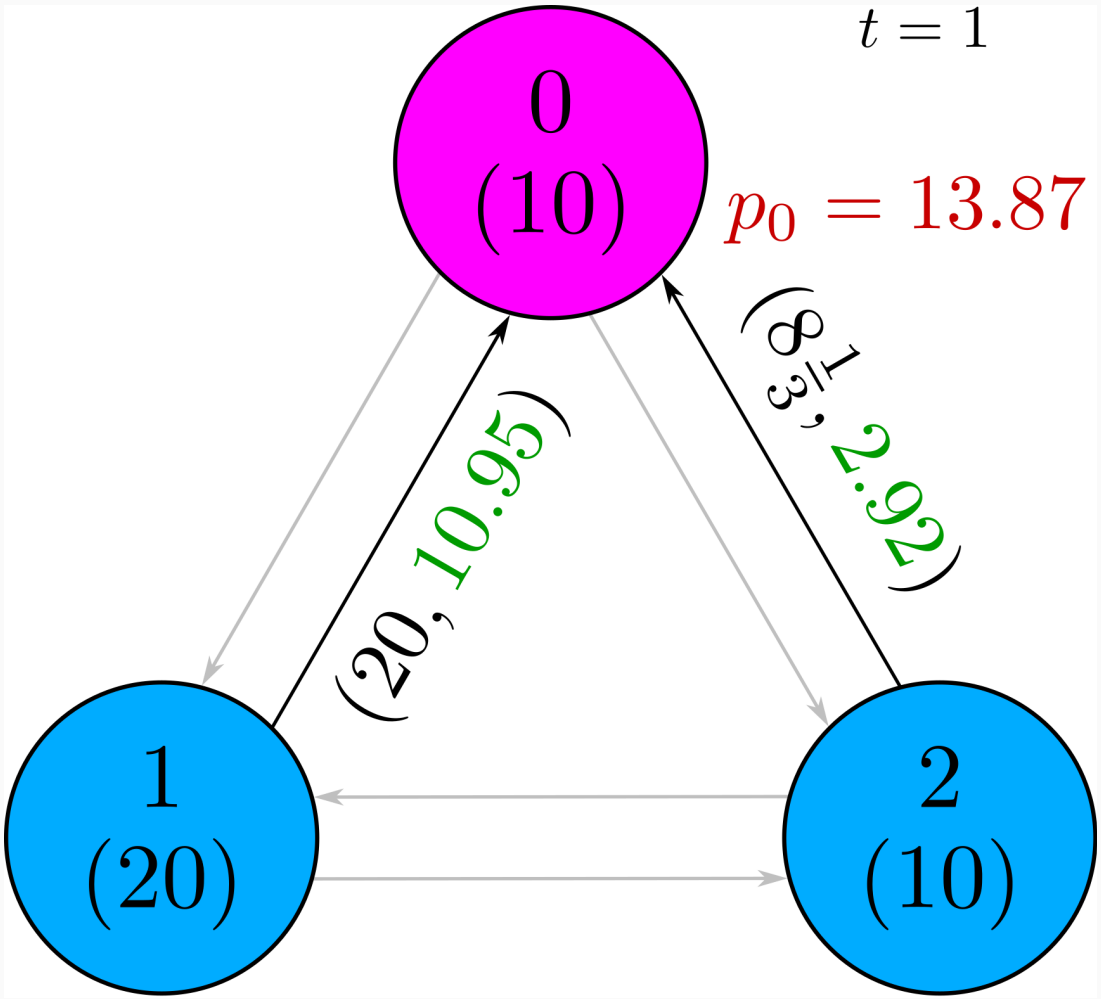

Summarized Results

Case	Payoff
Example 1 (ND)	**10**
Example 1 (D)	$9\frac{1}{3}$
Example 2 (ND)	13.68
Example 2 (D)	13.87

Strategy Simulator

Conclusions

- Homogeneous resource distributions
  - Any RF (trivially) NE
- Non-homogeneous resource distributions
  - NE not yet found

Symbolic Analysis

- Verified results of strategy simulator
- Mathematica notebook
- Intractable for nontrivial reciprocation functions
  - **Next step:** Alternative functions/representations

Implementation

- Beta strategy-integration into `go-ipfs`
- IPTB: IPFS nodes in Docker containers
- Scripted tests

Plan

Analytical Work

1. **Repeated game analysis**
   - Balances model accuracy with complexity
2. **Evolutionary game theory** (if time allows)
   - Good model, but high complexity

Simulations

1. **Strategy simulator**
   - Complements repeated game analysis
2. **Bitswap tests**
   - Test actual IPFS nodes

Timeline

May

- **Thesis**
  - Layout
  - Write intro/background, results so far
- **Implementation:** IPTB simulations
- **Simulation:** Continue evaluating strategies
- **Analytical:** Simplify intractable cases

June

- **Thesis**
  - Update results as they come
  - Plots and visualizations
  - Check formatting with writing center
- **Implementation:** IPTB simulations
- **Simulation:** Continue evaluating strategies
- **Analytical:** Evaluate results, re-orient

July

- **Thesis:** Primary focus
- **Implementation:** Finish up lingering work here