Driftwood: Self-Regulating Access to Natural Resources

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1 Intructions

On the coast of a distant country, people compete for the gathering of driftwood brought to the shore by storms. Whoever is first onto a stretch of the shore after high tide is allowed to take whatever they wish up to their carrying capacity and to gather it into a pile above the high-tide line. To indicate ownership, piles are marked by placing two stones on their top. The wood it contains is then regarded as the property of a driftwood collector. Only wood pile owners always respect pile ownership. Collectors having not yet established a pile can head towards wood piles and "steal" the wood it contains, but only when no pile owner is observing them.
An Agent-Based Model (ABM) based on this description will be used to explore the value of this "peer-pressure" regulation in addressing wood theft. Is it possible, without any external enforcement, to reach a stabilized situation?

1. **Extension 1:** Modify the agent-based model to explore variations in the recognition of pile ownership. Introduce the ability to steal for owners and analyze the impact on the stability of pile ownership over time.

2. **Extension 2:** Extend the model to introduce external factors, such as the arrival of external authorities or external enforcement mechanisms. Explore how the introduction of external influences affects the stability of the system and the behaviors of wood collectors.

3. **Extension 3:** Conduct an exploration exercise by varying the size of the wood collector groups. Investigate how the size of collector groups influences the emergence of stabilized situations, considering aspects like cooperation, competition, and the prevention of wood theft. Analyze the system's resilience to perturbations based on group size.

2 Core Mechanisms

2.1 Environment

The simulation models a coastal environment designed to study driftwood collection behaviors within a dynamic and visually clear framework. It incorporates a tripartite spatial structure, efficiently representing different coastal zones while balancing computational performance and detailed visual analysis.

Spatial Organization of the Environment

The environment's spatial layout, illustrated in Figure 1, is divided into three distinct regions, each fulfilling specific roles in the simulation:

- **Deep Sea Zone**: Shown in dark blue, this zone occupies 20% of the environment's width and maintains a constant sea level of 0 meters.
- **Tidal Zone**: Rendered in light blue, this region spans 20% to 65% of the environment's width and serves as the primary area for driftwood movement.
- **Sandy Beach Zone**: Represented in beige, this zone extends from the tidal zone to the environment's boundary, offering space for driftwood collection and pile formation.

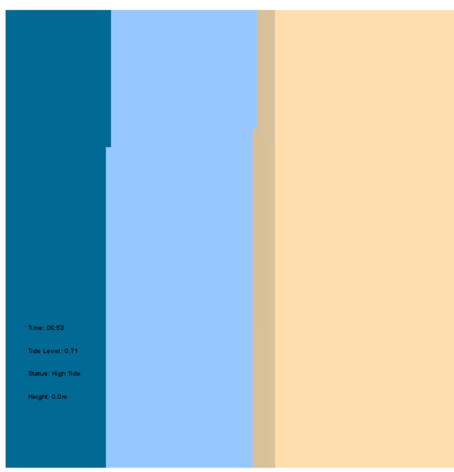

Figure 1: Base Environment

Day-Night and Tidal Cycles

The simulation incorporates a synchronized day-night cycle and tidal system, adding dynamic variability to the environment. The 24-hour day-night cycle features:

- **Daytime**: From 5:00 to 17:00.
- **Nighttime**: From 17:00 to 5:00.

The tidal system alternates between rising and falling tides in four distinct phases:

- **Rising tides**: 0:00–6:00 and 12:00–18:00.
- **Falling tides**: 6:00–12:00 and 18:00–24:00.

These cycles create fluctuating water levels that influence driftwood movement and collector behavior, providing a realistic and adaptive simulation environment.

Wave Dynamics

Wave behavior is governed by a parametric system that integrates amplitude, frequency, and speed to simulate realistic water movement. Sinusoidal functions are applied to calculate vertical positions and adjust patterns over time, directly impacting driftwood distribution across the environment.
To enhance computational efficiency, the simulation discretizes wave dynamics into a cell-based structure. Each cell holds key properties such as height, water depth, and wetness level, ensuring detailed and localized environmental modeling.

2.2 Extension 1: Collector Behavior and Pile Ownership

Extension 1 of the Driftwood model explores the dynamics of pile ownership and theft within a self-regulating system that operates without external enforcement. This extension introduces **Collector agents** with individualized characteristics, such as speed, carrying capacity, greediness, and field of view. These attributes shape their wood collection and theft behaviors, resulting in a complex interplay of resource gathering and protection strategies.

Collector Agents and Behavior

The **Collector agents** are implemented as shown in Figure 2 with a range of properties that influence their actions:

- **Speed**: Ranges from 0 to 8 km/h, adjusting dynamically based on carried wood weight and water depth.
- **Carrying Capacity**: Limited to a maximum of 10 wood pieces, representing the physical constraint on collection.
- **Greediness**: A randomly assigned value between 0.3 and 0.8, determining the agent's tendency to keep collecting wood or return to their pile.

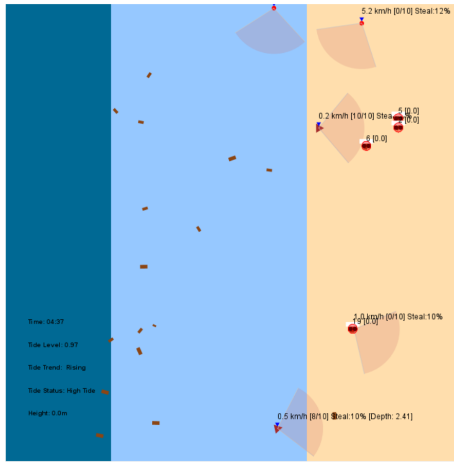

Figure 2: Collector Behavior and Pile Ownership

The wood collection process simulates realistic gathering behavior. Collectors detect wood only within their **field of view**, which spans 100 degrees and extends 10 meters. Upon detecting wood, the collector approaches it, adds it to their inventory if capacity allows, and updates their carried value. The decision to continue collecting or return to the pile is influenced by the collector's greed factor and current load.

Pile Management

Pile management is a central component of the model. Piles are created at random locations on the beach and visually marked with two stones. The value of a pile is calculated dynamically based on the number of contained wood pieces, while a **stability scoring system** monitors its resistance to theft over time.

Theft Mechanics

The theft mechanics introduce competition and risk into the system. Collectors without piles can attempt to steal from unobserved piles. The theft process involves:

- **Initial Steal Chance**: Set at 10%, increasing up to 20% with successful thefts.
- **Target Selection and Approach**: Careful planning is required to avoid detection by the pile owner.
- **Wood Removal**: Collectors attempt to discreetly remove wood pieces from the pile.

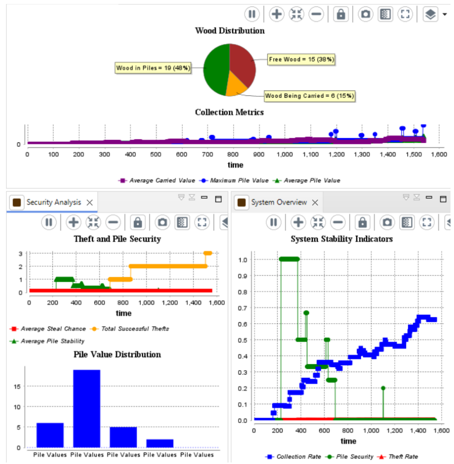

Figure 3: Collector Behavior and Pile Ownership Analysis

Visualization of Simulation Outcomes

To illustrate the outcomes of this extension, several figures from the simulation run are included. **Figure 3** provides a snapshot of the coastal environment, displaying collectors, wood pieces, and piles. This visual representation of spatial dynamics is useful for contextualizing the discussion.
Additional visual elements enhance the analysis:

- **Wood Distribution Pie Chart and Collection Metrics Graph**: These figures detail resource management and collection efficiency over time, highlighting the distribution of wood between free wood, carried wood, and wood in piles, as well as the evolution of average carried and pile values.

- **Theft and Pile Security Chart**: Displays metrics such as average steal chance, total successful thefts, and average pile stability, helping readers understand the balance between theft attempts and pile security.

- **System Stability Indicators Graph**: Shows collection rate, pile security, and theft rate over time, capturing the overall performance and stability of the self-regulating system.

2.3 Extension 2: External Authority and Enforcement

Extension 2 of the Driftwood model incorporates external enforcement mechanisms, introducing **Authority agents** and security cameras to regulate wood theft and enhance system stability. This formal surveillance and punishment system significantly impacts collector behavior and resource distribution.

Visualization of Enforcement Mechanisms

The coastal environment now features Authority agents, represented by green circles, and security cameras, shown as gray circles. These enforcement mechanisms are strategically distributed across the simulated area, as shown in Figure 4. This visual representation highlights the spatial arrangement of enforcement tools.

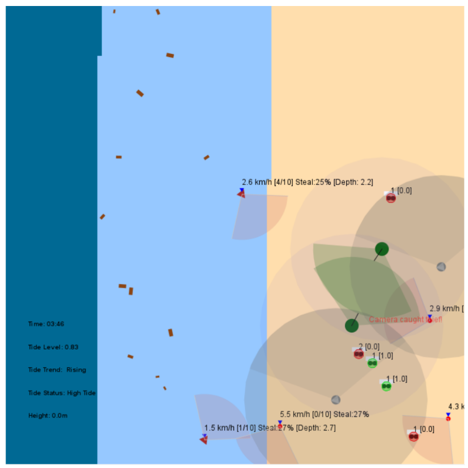

Figure 4: External Authority and Enforcement

Effectiveness of External Enforcement

The impact of external enforcement measures is illustrated in the "Authority Effectiveness" chart (Figure 5). Key observations include:

- **Cumulative Catches**: A steady increase over time, indicating consistent apprehension of thieves by Authorities.
- **Steal Chance**: A relatively stable average steal chance, suggesting that the presence of Authorities maintains a deterrent effect.
- **System Stability**: Gradual improvement throughout the simulation, demonstrating the positive influence of enforcement on system order.

Security Coverage and Resource Distribution

The "Security Coverage" pie chart (Figure 5) shows the distribution of surveillance:

- **Uncovered Area**: 91%, representing the majority of the environment.

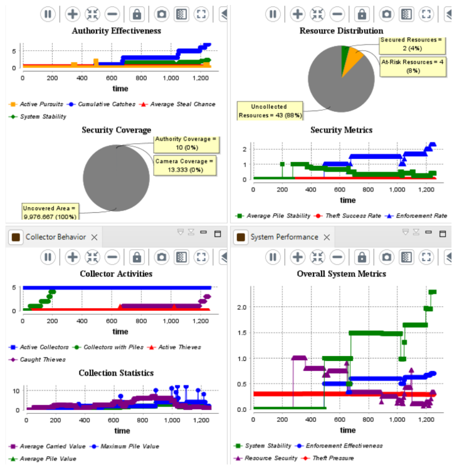

Figure 5: External Authority and Enforcement Analysis

- **Authority Coverage**: 6%, focusing on strategic locations.
- **Camera Coverage**: 3%, complementing Authority agents.

This targeted but limited coverage influences collector behavior, reducing theft occurrences.
The "Resource Distribution" chart provides insights into resource allocation:

- **Uncollected Resources**: 89%, indicating a cautious collection process due to enforcement presence.
- **Secured Resources**: 4%, representing wood in protected piles.
- **At-Risk Resources**: 6%, reflecting ongoing competition for resources.

Security Metrics and Collector Activities

The "Security Metrics" graph (Figure 5) reveals dynamics between enforcement and theft:

- **Enforcement Rate**: Increasing over time, aligning with the cumulative catches observed.
- **Pile Stability**: Relatively stable, indicating consistent protection of collected resources.
- **Theft Success Rate**: Fluctuates, reflecting the balance between enforcement and theft attempts.

The "Collector Activities" chart offers a detailed view of behavior:

- **Active Collectors and Pile Owners**: Consistent numbers suggest stable legitimate activity.
- **Active Thieves and Caught Thieves**: Periodic spikes indicate cycles of theft attempts and apprehensions.

Overall System Metrics

The "Overall System Metrics" graph encapsulates the cumulative effects of enforcement through four key metrics:

- **System Stability**: Gradually increases, peaking at the end of the simulation, indicating a more predictable environment.
- **Enforcement Effectiveness**: Shows steady growth, correlating with cumulative catches.
- **Resource Security**: Fluctuates, reflecting the dynamic balance between theft and protection.
- **Theft Pressure**: Declines over time, aligning with increased enforcement effectiveness and stability.

The interplay between these metrics demonstrates a clear trend towards a more stable and secure system as enforcement effectiveness rises and theft pressure diminishes. While short-term fluctuations persist, the long-term outcome is improved system order and reduced resource theft.

2.4 Extension 3: Group Dynamics and System Resilience

Extension 3 introduces sophisticated **group formation mechanics** and **perturbation analysis** to examine the impact of social structures on resource collection efficiency and overall system stability. The implementation demonstrates several key findings regarding group dynamics, system resilience, and the balance between individual and collective strategies.

Group Formation Mechanics

The model shows that collectors naturally organize into groups of 2 to 4 members, with:

- **Group Formation Probability**: 30%.
- **Breakup Probability**: 10%.
- **Cooperation Bonus**: Enhances carrying capacity by a percentage and improves collection efficiency.

As shown in Figure 6, collectors operating in groups (indicated by matching colors and L-M designations) exhibit coordinated behaviors, demonstrating the successful implementation of group formation mechanics. These groups achieve greater efficiency in resource collection compared to individual collectors.

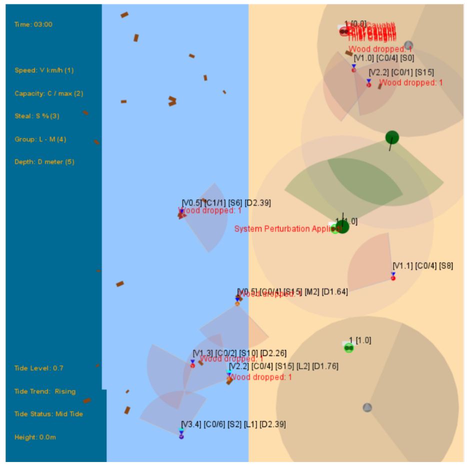

Figure 6: Group Dynamics and System Resilience

Response to Perturbations

The system's response to disruptions reveals fascinating patterns in resource management and group resilience:

- **Recovery Rate**: Groups consistently recover at high levels (above 80%), as illustrated by the **Performance Metrics graph** in Figure 7. Perturbation levels (shown as spikes) result in rapid recovery, indicating the system's robust response to external disruptions.
- **Group Defense Rate**: The **Security Overview graph** (Figure 7) shows that groups maintain a higher defense rate (green line) compared to individual collectors, especially during periods of increased theft attempts. This highlights the role of group formation as an effective theft deterrent.

Resource Distribution Patterns

Resource distribution patterns emphasize the advantages of group formation:

- The **Resource Distribution graph** in Figure 7 shows that grouped collectors (blue line) consistently maintain higher resource accumulation rates compared to individual collectors (red line).
- Periodic spikes in group resource collection suggest coordinated and efficient collection efforts.

Group Statistics and System Stability

The **Group Statistics pie chart** reveals the following distribution among collectors:

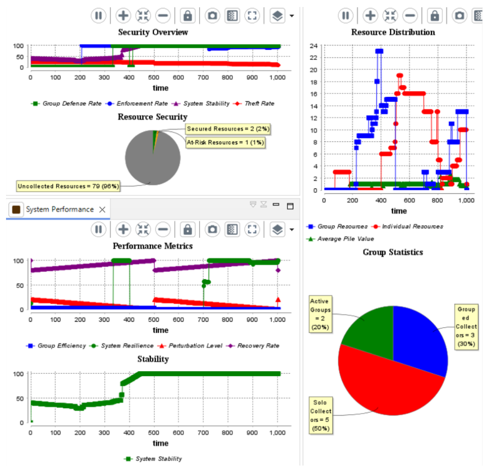

Figure 7: Group Dynamics and System Resilience Analysis

- **Independent Collectors**: 50%.
- **Active Groups**: 30%.
- **Groups in Formation**: 20%.

This balanced distribution creates an optimal dynamic for system stability, as evidenced by the consistent **System Stability metric** in the bottom graph of Figure 7.

Perturbation Tests

System perturbation tests, conducted at 500-cycle intervals with 20% strength and 500-cycle recovery periods, highlight differential impacts on grouped versus individual collectors:

- Grouped collectors maintain higher stability during perturbation events, as evidenced by their superior recovery rates.
- A proposed additional figure could show comparative recovery rates, further illustrating this resilience.

Group Size and System Stability

Analysis reveals that larger groups (up to the maximum size of 4) correlate with higher system stability scores. A proposed figure could demonstrate the relationship between group size and stability over time, providing deeper insights into the advantages of collective strategies.

3 Conclusion

This Agent-Based Model demonstrates the emergence of stable resource management through three key extensions:

1. Extension 1 showed that peer pressure and self-regulation can effectively manage resource collection through pile ownership and theft prevention systems.
2. Extension 2 revealed that external enforcement through authorities and cameras significantly improves system stability and reduces theft behavior.
3. Extension 3 demonstrated that group formation enhances both collection efficiency and system resilience, while providing protection against perturbations.

The model successfully illustrates that a combination of social pressure, formal enforcement, and group cooperation can create stable resource management without requiring complex control mechanisms.

4 Appendix

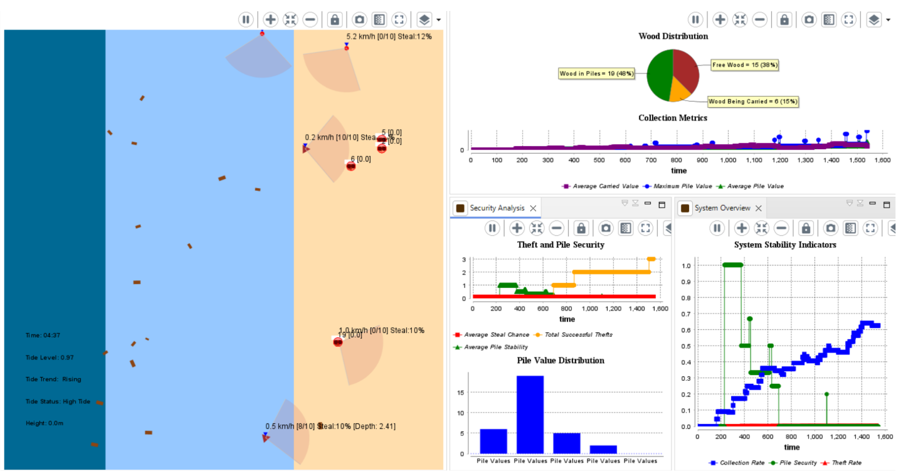

Figure 8: Collector Behavior and Pile Ownership

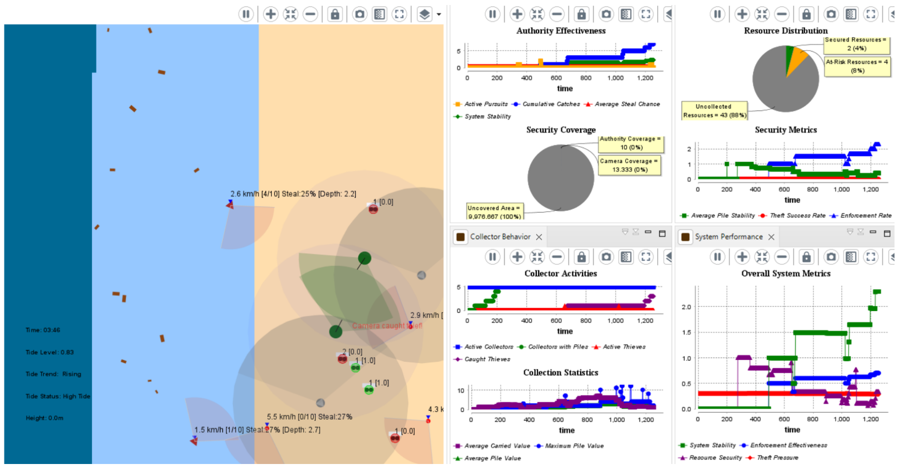

Figure 9: External Authority and Enforcement

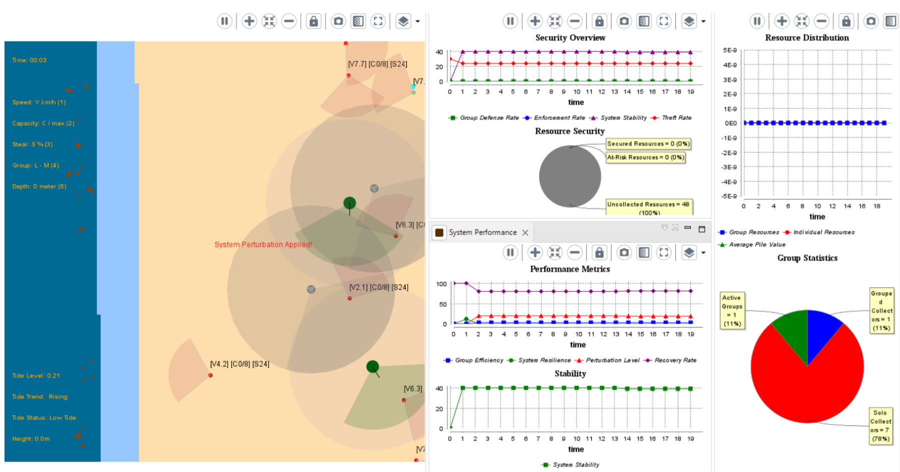

Figure 10: Group Dynamics and System Resilience in early stage

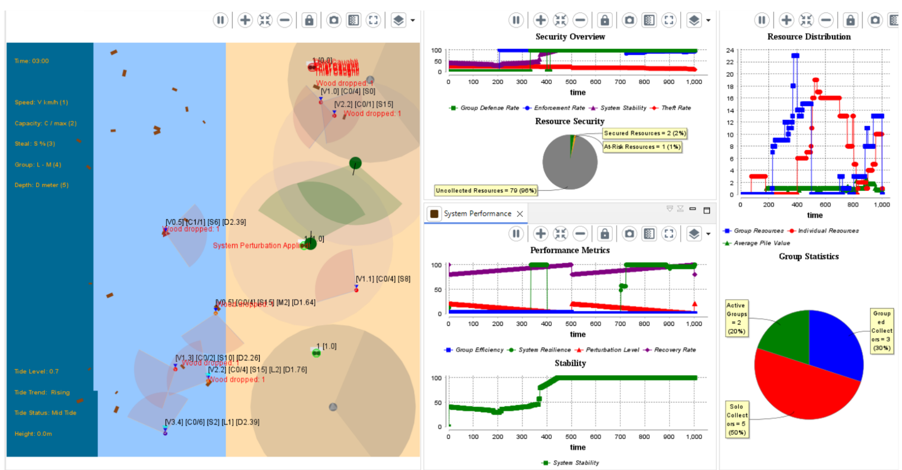

Figure 11: Group Dynamics and System Resilience