Driftwood: Self-Regulating Access to Natural Resources

Pham Gia Phuc
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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 environment represents a coastal area with distinctive zones and dynamic environmental factors, provides a dynamic backdrop for the simulation, with its various components working together to create realistic coastal conditions that directly influence agent behavior and resource distribution. This section details the key components and mechanisms of the environment.

2.1.1 Spatial Layout

The environment is structured into three main zones:

- Deep Sea Zone: Occupies 20% of the environment width
- Tidal Zone: Spans from 20% to 65
- Sandy Beach: Extends from 65% to the environment boundary

The terrain has a varying height profile:

- Deep Sea: Maintained at 0 meters (sea level)
- Beach: Rises linearly from sea level to a maximum height of 5 meters
- Slope: Calculated dynamically based on the distance from sea to beach end

2.1.2 Time and Tidal System

The simulation implements a comprehensice day-niht cycle and tidal system:
Day-Night Cycle

- 24-hour cycle with configurable time progression speed
- Night period: 17:00 (5 PM) to 5:00 (5 AM)
- Day period: 5:00 (5 AM) to 17:00 (5 PM)

Tidal Cycle
Synchronized with day-night cycle, the tidal system follows a complex as follow:

1. Rising Tide (0:00-6:00): Water level increases, pushing towards shore
2. Falling Tide (6:00-12:00): Water recedes towards the sea
3. Rising Tide (12:00-18:00): Second daily high tide
4. Falling Tide (18:00-24:00): Final daily recession

Whereas, the tide parameters include:

- Base level: 0.15 (minimum water level)
- Minimum tide: 0.15
- Maximum tide: 1.0
- Adjustable tide speed

2.1.3 Wave Dynamics

The wave system adds realistic water movement through:
Wave Parameters

- Amplitude: Controls wave height
- Frequency: Determines wave pattern
- Speed: Controls wave movement rate
- Base level: Ensures minimum wave height

Wave effects are calculated using sinusoidal functions that consider:

- Vertical position (Y-coordinate)
- Simulation time
- Multiple wave frequencies for complex patterns

2.1.4 Beach Cll Properties

Each cell in the environment grid maintains:

- Height: Calculated based on distance from sea
- Water depth: Dynamic calculation based on tide and waves
- Wetness: Tracks moisture level after water exposure
- Color states:
  - Deep water: Constantly stay in the left most part of the environment
  - Shallow water: Overlapping region where the water meets the dry sandy beach
  - Dry sand: Constantly stay in the right most part of the environment
  - Wet sand: Dynamically calculated based on wetness level

2.1.5 Environmental Interactions

The environment facilitates various interactions:
Wetness Mechanics

- Sand remains wet for a configurable duration after water exposure
- Wetness gradually decreases over time
- Visual feedback through color gradients

Wave-Tide Integration

- Waves affect water movement in both deep and shallow zones
- Combined effects of waves and tides influence driftwood movement
- Dynamic calculation of water boundaries based on wave and tide states

2.1.6 Performance Optimization

Several optimization mechanisms are implemented:

- Spatial step calculations for movement efficiency
- Cell update frequency optimization (every 2 cycles)
- Conditional updates based on cell location and state
- Caching of wave calculations where possible

2.2 Extension 1: Collector Behavior and Pile Ownership

This extension introduces the Collector agents and implements the core wood-gathering mechanics, including pile ownership and theft dynamics. The extension explores how collectors interact with driftwood resources and each other through a system of ownership recognition and peer pressure.

2.2.1 Collector Agent Characteristics

Basic Properties

- Speed: Variable movement rate (0-8 km/h)
- Carrying Capacity: Maximum value of wood pieces that can be carried (default: 10)
- Greediness: Random value between minimum (0.3) and maximum (0.8) affecting collection behavior
- Field of View (FOV):

- View angle: 100 degrees
- View distance: 10 meters
- Dynamic FOV calculations with caching for performance

Movement and Navigation

1. Speed Adjustments:
   - Reduced by carried wood weight (proportional to value)
   - Further reduced in water based on depth
   - Minimum speed maintained at 0.5 km/h in water
   - Random speed variations for natural movement
2. Environmental Interaction:]
   - Water depth affects movement speed
   - Terrain navigation with spatial optimization
   - Wandering behavior when not actively collecting

2.2.2 Wood Collection System

Collection Mechanics

1. Wood Detection:
   - Only wood within FOV is visible
   - Targeting system for nearest available wood
   - Validation of wood availability and carrying capacity
2. Collection Process:
   - Approach detected wood pieces
   - Add to carried inventory if capacity allows
   - Update carried value and wood status
   - Decision-making for continued collection based on greed factor

Pile Management

1. Pile Creation:
   - Established at random location on beach
   - Marked with two stones (visual indicators)
   - Ownership tracking system
   - Value calculation based on contained wood pieces

2. Pile Properties:
    - Dynamic value updates
    - Stability scoring system
    - Creation time tracking
    - Theft monitoring capabilities

2.2.3 Theft Mechanics

Stealing Behavior

1. Initial Parameters:
    - Base steal chance: 10%
    - Maximum steal chance: 20%
    - Chance increase: 1% per successful theft
2. Theft Conditions:
    - Target pile must be unobserved by owner
    - Pile must be within thief's FOV
    - Thief must have available carrying capacity

Theft Process

1. Target Selection:
    - Evaluation of potential targets
    - Validation of steal conditions
    - Risk assessment based on owner presence
2. Execution:
    - Approach target pile
    - Wood removal process
    - Update pile and thief statistics
    - Escape mechanics

2.2.4 Stability Mechanisms

Pile Stability

1. Stability Calculation:
    - Based on theft frequency
    - Time factor consideration

- Value preservation tracking

2. Stability Indicators:
   - Visual feedback system
   - Numerical stability score
   - Dynamic updates based on events

System Resilience

1. Self-Regulation:
   - Peer pressure through observation
   - Risk-reward balance in theft attempts
   - Dynamic adjustment of theft probabilities

2. Balance Mechanisms:
   - Carrying capacity limitations
   - Speed penalties for loaded collectors
   - FOV restrictions for observation

2.2.5 Monitoring and Statistics

1. Performance Metrics:
   - Pile value tracking
   - Theft success rates
   - System stability measurements
   - Collection efficiency statistics

2. Visual Feedback:
   - FOV visualization
   - Pile ownership indicators
   - Theft attempt warnings
   - Status displays for collectors and piles

The extension successfully implements a self-regulating system where collector behavior is influenced by both individual characteristics and peer observation. The balance between collection efficiency and theft risk creates emergent patterns of resource distribution and social interaction.

2.3 Extension 2: External Authority and Enforcement

Extension 2 introduces external enforcement mechanisms through Authority agents and security cameras, implementing a formal system of surveillance and punishment to regulate wood theft. This extension explores how external enforcement affects system stability and collector behavior.

2.3.1 Authority Agents

Core Characteristics

- Field of View: 120 degrees (wider than collectors)
- View Distance: 15 meters (extended range)
- Movement Speed: 1.5 units (faster than average collector)
- Detection Radius: 20 meters for suspicious activity

Authority Types

1. Patrol Authority
   - Dynamic movement between patrol points
   - Route optimization based on suspicious activity
   - Periodic patrol route changes
   - Active pursuit capabilities
2. Stationary Authority
   - Fixed position monitoring
   - Rotation for 360-degree coverage
   - Enhanced detection of nearby activities
   - Focused area surveillance

2.3.2 Surveillance Systems

Security Cameras

- Deployment: Random positions on beach
- Properties:
  - Detection radius: 20 meters
  - Rotation speed: 2.5 degrees per step
  - View angle: 120 degrees
  - Continuous scanning motion

Detection Mechanics

1. Visual Coverage:
    - Overlapping surveillance zones
    - Dynamic FOV calculations
    - Real-time monitoring capabilities
2. Threat Assessment:
    - Suspicious behavior detection
    - Theft attempt identification
    - Group activity monitoring
    - Proximity analysis to wood piles

2.3.3 Enforcement Mechanisms

Punishment System

1. Fine Implementation:
    - Reduction in steal chance
    - Wood pile value penalties
    - Escalating punishments for repeat offenders
2. Catch Mechanics:
    - Immediate theft interruption
    - Resource confiscation
    - Behavioral modification through penalties
    - Warning message generation

Active Pursuit

1. Pursuit Triggers:
    - Direct theft observation
    - Suspicious proximity to piles
    - Reported theft attempts
    - Pattern recognition of theft behavior
2. Pursuit Protocol:
    - Target tracking
    - Speed boost during chase
    - Interception calculations
    - Coordinated pursuit with multiple authorities

2.3.4 System Integration

Authority-Collector Interaction

1. Behavioral Impact:
   - Modified theft risk assessment
   - Enhanced awareness of surveillance
   - Adaptive collection strategies
   - Evasion behavior development
2. Resource Protection:
   - Increased pile stability
   - Reduced theft frequency
   - Protected zones establishment
   - Community behavior modification

Surveillance Network

1. Coverage Optimization:
   - Strategic camera placement
   - Patrol route efficiency
   - Zone defense coordination
   - Blind spot minimization
2. Information Sharing:
   - Authority coordination
   - Threat level assessment
   - Resource allocation
   - Response prioritization

2.3.5 Performance Metrics

Enforcement Effectiveness

1. Quantitative Measures:
   - Total catches tracked
   - Theft attempt success rates
   - System stability calculations
   - Response time analytics
2. System Impact:

- Pile value preservation
- Theft deterrence rates
- Behavioral modification success
- Overall system stability

Visual Feedback

1. Real-time Indicators:
   - Authority status display
   - Pursuit visualizations
   - Warning messages
   - Coverage zone mapping
2. Statistical Tracking:
   - Catch count monitoring
   - Active pursuit tracking
   - System stability graphing
   - Effectiveness trending

2.3.6 Environmental Adaptation

Dynamic Response

1. Time-based Adjustments:
   - Day/night patrol modifications
   - Tide-influenced coverage
   - Weather condition adaptation
   - Peak activity period focus

   - High-risk area identification
   - Resource concentration monitoring
   - Patrol route optimization
   - Coverage gap analysis
2. Spatial Optimization:

The extension successfully implements a comprehensive external enforcement system that significantly impacts collector behavior and system stability. The combination of mobile authorities and fixed surveillance creates a dynamic security environment that adapts to changing theft patterns and resource distribution.

2.4 Extension 3: Group Dynamics and System Resilience

Extension 3 implements collector group formation mechanics and system perturbation analysis, examining how social structures affect resource collection efficiency and system stability under stress.

2.4.1 Group Formation Mechanics

Group Parameters

1. Size Constraints:
    - Minimum group size: 2 members
    - Maximum group size: 4 members
    - Dynamic size adjustment based on performance
2. Formation Probability:
    - Base formation chance: 30%
    - Breakup chance: 10%
    - Group cohesion radius: 5 units

Group Structure

1. Leadership Roles:
    - Designated group leader
    - Member coordination
    - Resource sharing strategies
    - Group movement patterns
2. Member Benefits:
    - Increased carrying capacity (+20% cooperation bonus)
    - Enhanced pile protection
    - Shared information
    - Coordinated collection strategies

2.4.2 Group Behavior

Coordination Mechanics

1. Movement Coordination:
    - Group cohesion maintenance
    - Leader-follower dynamics

- Collective resource targeting
- Formation maintenance

- Shared pile protection
- Collective theft deterrence
- Efficient wood collection
- Territory establishment

2. Resource Management:

Group Efficiency

1. Performance Metrics:
    - Collection rate tracking
    - Resource distribution
    - Protection effectiveness
    - Group stability measurement

    - Size optimization
    - Role reassignment
    - Strategy adjustment
    - Territory expansion/contraction

2. Adaptation Mechanisms:

2.4.3 Perturbation System

Perturbation Parameters

- Strength: 0.2 (20% impact)
- Interval: 500 cycles
- Recovery Time: 500 cycles
- Impact Areas: Speed, capacity, efficiency

Implementation Mechanics

1. Effect Application:
    - Speed reduction
    - Capacity limitation
    - Efficiency decrease
    - Resource loss

2. Recovery Process:
    - Gradual capability restoration
    - Adaptive response
    - Group reorganization
    - System stabilization

2.4.4 System Resilience

Stability Metrics

1. Group Stability Index:
    - Formation duration
    - Member retention
    - Collection efficiency
    - Protection effectiveness

    - Resource distribution
    - Theft resistance
    - Recovery speed
    - Adaptation effectiveness
2. System Performance:

Resilience Analysis

1. Group Impact:
    - Size influence on stability
    - Formation effectiveness
    - Protection capability
    - Recovery contribution
2. System Adaptation:
    - Response to perturbations
    - Group reorganization
    - Resource reallocation
    - Strategy modification

2.4.5 Performance Monitoring

Group Analytics

1. Efficiency Metrics:
    - Collection rates
    - Protection success
    - Member contribution
    - Resource optimization

    - Group longevity
    - Member satisfaction
    - Resource security
    - Perturbation resistance

2. Stability Indicators:

System Evaluation

1. Performance Tracking:
    - Group formation rates
    - System stability
    - Recovery efficiency
    - Adaptation success
2. Visual Feedback:
    - Group identifiers
    - Member status
    - Performance indicators
    - System state visualization

2.4.6 Environmental Interaction

Group Adaptation

1. Environmental Response:
    - Tide cycle adaptation
    - Territory adjustment
    - Resource targeting
    - Protection strategies

2. Collective Behavior:
    - Coordinated movement
    - Resource sharing
    - Threat response
    - Information exchange

2.4.7 System Dynamics

Emergent Behavior

1. Social Structures:
    - Group hierarchy
    - Territory establishment
    - Cooperation patterns
    - Competition dynamics
2. System Properties:
    - Self-organization
    - Adaptive response
    - Collective resilience
    - Stable configurations

The extension successfully demonstrates how group formation influences system stability and resilience. The introduction of perturbations provides insights into the system's adaptive capabilities and the effectiveness of collective strategies in maintaining stable resource distribution patterns.

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.