Final Project Proposals

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1 Boids Flocking Algorithm

I propose to implement Reynolds' original Boids algorithm [3], which simulates the flocking behavior of birds through three simple steering behaviors:

- *Separation*: Avoid crowding nearby flockmates
- *Alignment*: Steer towards the average heading of nearby flockmates
- *Cohesion*: Steer towards the average position of nearby flockmates

Each boid will be modeled as a particle as follows:

- Position, velocity and acceleration vector.
- Max. Speed and steering force limitations.
- A radius for defining which other boids it can "see".

For each time step of the simulation the following steps would be computed:

1. Compute seperation, alignment and cohesion
2. Apply weights to each force
3. Update velocity and position using time integration.
4. Handling periodic boundary condition.
5. Render simulation state.

the following parameters could than be systematically change to explore the systems behavior:

- Neighborhood radius
- Weights of forces
- Flock size

1.1 Implementation Plan

1. **Basic Model Implementation**
   - Create a particle class with position, velocity, acceleration vectors, and perception radius
   - Implement the three core steering behaviors:
     - Separation: Avoid crowding nearby flockmates
     - Alignment: Steer towards the average heading of nearby flockmates
     - Cohesion: Steer towards the average position of nearby flockmates
   - Apply force limitations (max. speed and steering force)
   - Implement periodic boundary conditions for continuous movement
   - Develop a visualization system to render boids with directional indicators
2. **Parameter Exploration**
   - Systematically vary and document the effects of:
     - Neighborhood radius (perception distance)

  - Relative weights of each steering force
  - Flock size and density
  - Time step size for numerical integration
- Record emergent patterns and phase transitions between different flocking behaviors

3. **Extensions and Analysis**
These are possible extensions, where I would implement a subset of them:
   - **Obstacle Avoidance and Environmental Factors**
     - Add obstacle avoidance steering behavior
     - Add wind or similar effects that influence movement
     - Create a food source that attracts the flock
   - **Leadership Dynamics**
     - Implement a "follow the leader" steering behavior
     - Explore different types of leadership (fixed, emergent, rotating)
   - **Predator-Prey Dynamics**
     - Implement a predator with different movement patterns
     - Give the flock a mechanism to avoid the predator
     - Analyze how flocking provides protection against predation
   - **Advanced Perception Model**
     - Replace simple radius-based perception with vision cones

2 Forest Fire Model

This paper [2] presents a cellular automata approach to forest fire simulation that can be enhanced with particle methods. While traditional CA models use grid cells, a particle-based representation allows for more realistic fire dynamics and environmental interactions.

2.1 Implementation Plan

1. **Basic CA-Particle Hybrid Model**
   - Implement a 2D grid where each cell can be in states like "fuel" (unburned), "burning", or "burned"
   - Create a particle system where fire is represented by discrete particles with:
     - Position and velocity vectors
     - Temperature/intensity attributes
     - Lifetime properties
   - Implement state transition rules:
     - A burning cell generates fire particles
     - Fire particles propagate based on environmental factors
     - Fuel cells ignite based on proximity to fire particles and probabilistic rules
     - Burned cells remain in a non-flammable state
2. **Environmental Factors Integration**
   - Implement wind as a vector field affecting particle movement
   - Model terrain topography influencing fire spread (uphill spread accelerates)
   - Add fuel heterogeneity with different burn probabilities and intensities
   - Incorporate moisture content affecting ignition probability
3. **Validation and Analysis**
   - Measure fire front propagation rates under different conditions
   - Analyze emergent fire patterns and shapes

3 Agent-based modeling of a multi-room multi-floor building emergency evacuation

This paper [1] extends particle-based models to more complex building environments, examining how multi-room and multi-floor architectures affect evacuation dynamics. The authors use the social force model to simulate the movement of agents through realistic building layouts with rooms, hallways, and staircases.

3.1 Implementation Plan

1. **Complex Building Geometry Implementation**
   - Extend the boids framework to implement wall elements and complex floor plans:
     - Create rooms, hallways, staircases, and exits using wall elements
     - Implement pedestrian-wall interactions with repulsive forces
     - Add capabilities for multi-floor simulations
   - Implement social force interactions between agents:
     - Motivational force (desired direction)
     - Psychological repulsive tendency
     - Compression forces
     - Viscous damping effects
     - Sliding friction
2. **Evacuation Scenario Analysis**
   - Study the effects of:
     - Room door sizes
     - Main exit dimensions
     - Friction coefficients between pedestrians
     - Desired speeds (panic levels)
   - Investigate congestion patterns at doorways and exits
   - Analyze the "faster is slower" effect in various building configurations
3. **Comparative Analysis**
   - Compare evacuation dynamics between:
     - Single-room vs. multi-room configurations
     - Single-floor vs. multi-floor scenarios
   - Analyze how room door size and main exit dimension interact to affect overall evacuation efficiency

References

[1] Vi Ha and George Lykotrafitis. "Agent-based modeling of a multi-room multi-floor building emergency evacuation". In: *Physica A: Statistical Mechanics and its Applications* 391.8 (2012), pp. 2740–2751. ISSN: 0378-4371. DOI: https://doi.org/10.1016/j.physa.2011.12.034. URL: https://www.sciencedirect.com/science/article/pii/S0378437111009708.

[2] J. Quartieri et al. "A Cellular Automata Model for Fire Spreading Prediction". In: *International Conference on Urban Planning and Transportation - Proceedings* (July 2010).

[3] Craig W. Reynolds. "Flocks, herds and schools: A distributed behavioral model". In: *SIGGRAPH Comput. Graph.* 21.4 (Aug. 1987), pp. 25–34. ISSN: 0097-8930. DOI: 10.1145/37402.37406. URL: https://dl.acm.org/doi/10.1145/37402.37406 (visited on 04/21/2025).