# Anatomy of a physics engine

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# Who am I?

- Studied Computer Science 2005-2009
  - 3rd and 4th year projects: physics engines
- Now:
  - Freelance programmer
  - Hobbyist game developer

# What is a physics engine?

- Simulates movement of objects
  - Position; orientation
  - Velocity; rotational velocity
- Models constraints between objects
  - Most common: non-penetration
  - Also: joints, friction, springs, buoyancy
- Here's one I made earlier...

# Demo

(A demo is worth a thousand pictures)

**Large Polygon Collider**
4th year group project 2008-2009

http://www.draknek.org/physics/

# What's the point?

- Games
  - Almost always need non-penetration
  - Almost always need collision detection
  - Almost always need collision resolution
- A physics engine provides all these
  - To some approximation of reality
  - But you may or may not want reality

# How does this relate to graphics?

- Same areas of maths
  - Vectors
  - Matrices
- Some shared algorithms
  - Collision pruning/visibility culling
  - Point-in-polygon test
- Interactive technology
  - Real-time requirements
  - Always needs to be faster

# Accuracy vs. efficiency

- True physics is computationally ridiculous
- We want plausibility not accuracy
- So for a real-time system we simplify things
  - Move objects and then resolve problems
  - Simplify collision geometry
  - “Sleep” non-moving objects
- If we can fake something, we probably should

# Two types of physics engine

- Mass-aggregate systems
  - Everything is a particle
  - Soft-body physics
  - Fluid simulation
  - Good for GPUs
- Rigid body simulators
  - Everything has position **and** orientation
  - Good for solid objects

# Structure of a physics engine

1. Broadphase
   - Determines which objects could potentially be colliding
2. Generate contacts
   - Performs collision detection and finds contacts
3. Resolve contacts
   - Find new (valid) positions for all objects

# 1. Broadphase (collision culling)

- Brute force collision testing would take O($n^2$) comparisons
- We can rule some collisions out very quickly
  - Bounding boxes
  - Exploiting spacial coherence
  - Exploiting temporal coherence

# 1. Broadphase (collision culling)

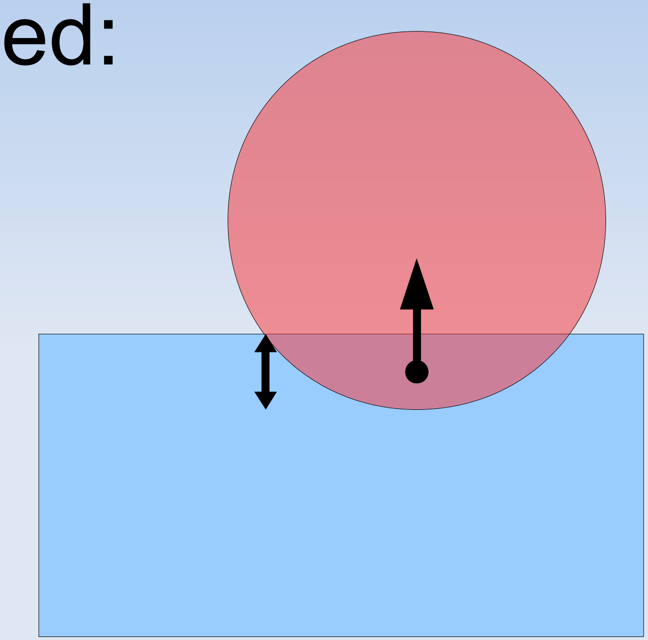
- Many implementations:
  - Bounding boxes for all pairs
  - Regular grid
  - Quadtree/Octree
  - BSP tree (binary space partitioning)
  - Hierarchy of bounding shapes
  - Sort and sweep algorithm

# 2. Collision detection

- Bad collision detection means bad physics
- Different levels of collision detection:
  - Intersection
    - Are these two shapes touching?
  - Collision
    - If these two shapes touch, tell me how and where
  - Temporal collision
    - Tell me how, where and also when

# 2. Contact generation

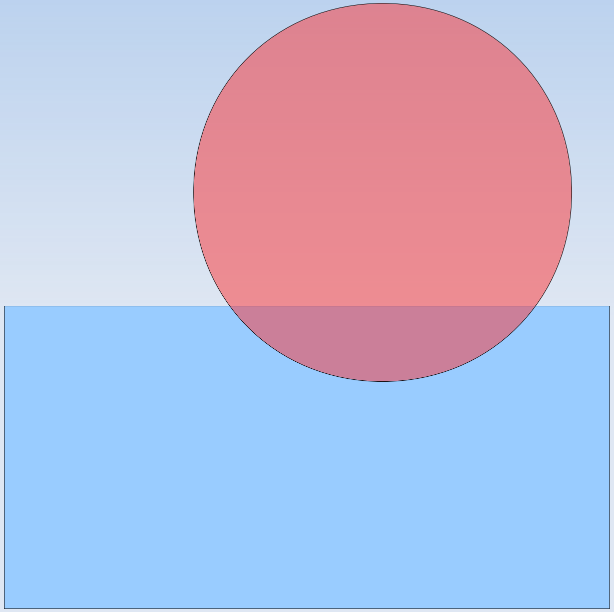
- Information generally needed:
  - Contact point
  - Contact normal
  - Amount of penetration



- For convex shapes in 2D, this isn't too hard
  - Concave shapes more difficult
  - 3D **much** more difficult

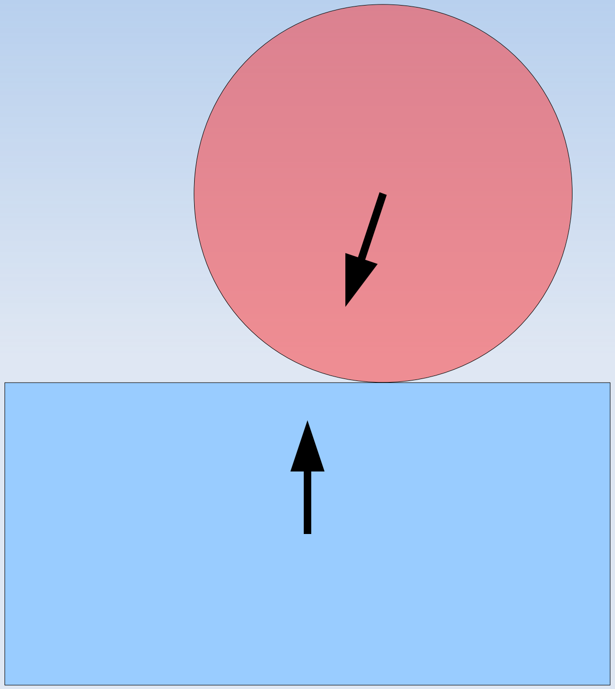
# 3. Collision resolution

- Remove penetration



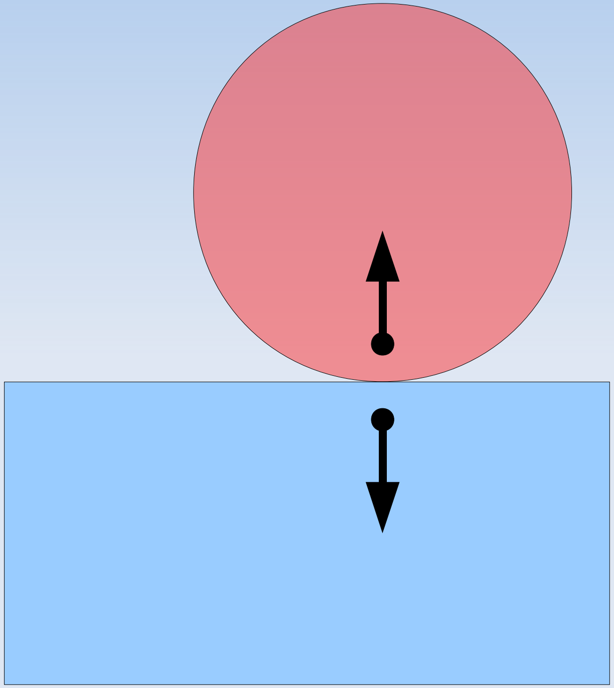
# 3. Collision resolution

- Remove penetration
- Calculate new velocities



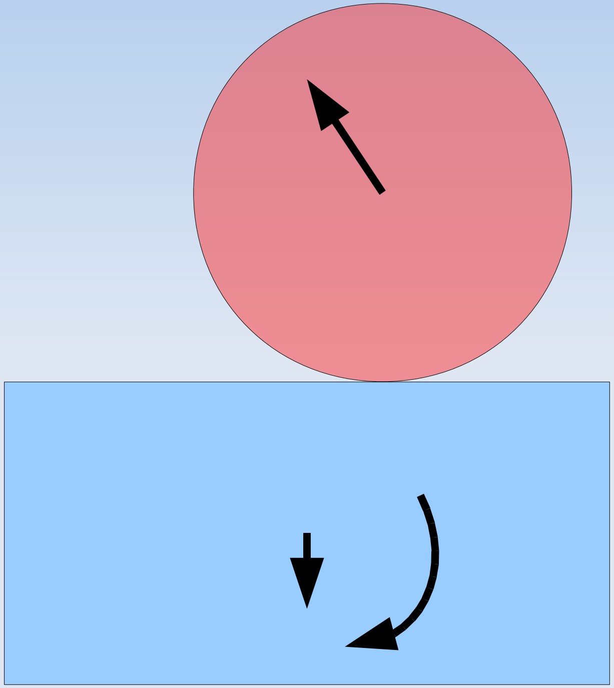
# 3. Collision resolution

- Remove penetration
- Calculate new velocities
  - Apply impulse at contact
  - Conservation of momentum
  - Coefficient of restitution



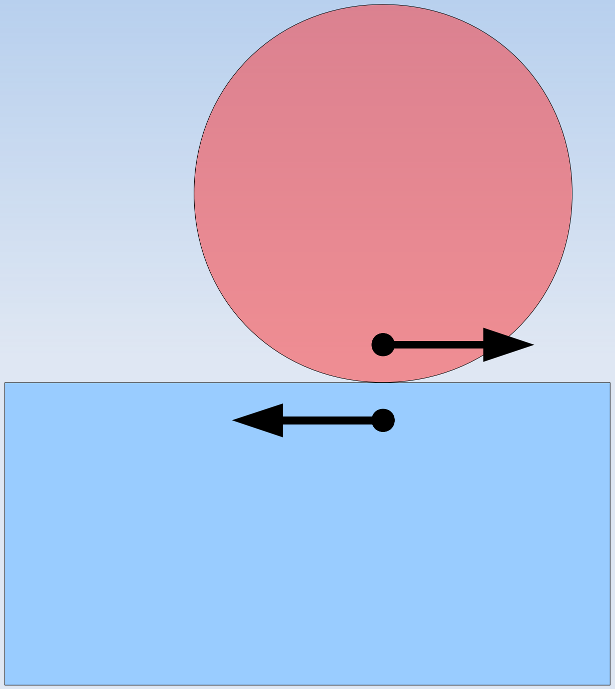
# 3. Collision resolution

- Remove penetration
- Calculate new velocities
  - Apply impulse at contact
  - Conservation of momentum
  - Coefficient of restitution
  - Includes rotation



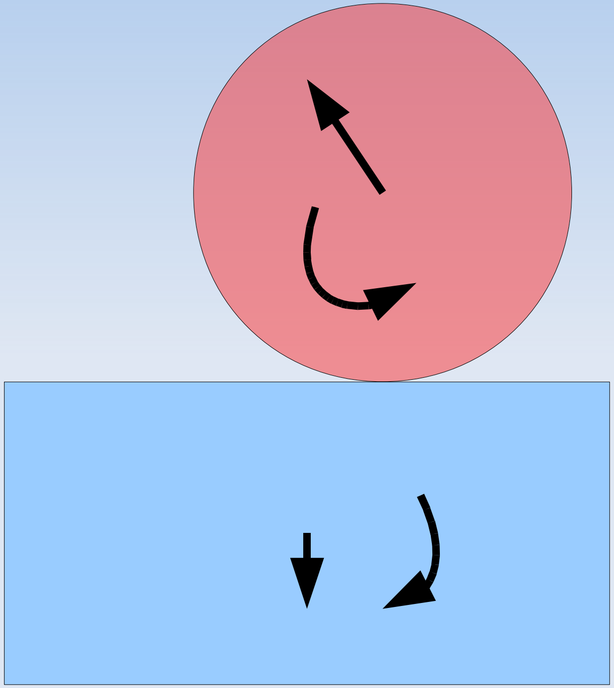
# 3. Collision resolution

- Remove penetration
- Calculate new velocities
  - Apply impulse at contact
  - Conservation of momentum
  - Coefficient of restitution
  - Includes rotation
  - Includes friction



# 3. Collision resolution

- Remove penetration
- Calculate new velocities
  - Apply impulse at contact
  - Conservation of momentum
  - Coefficient of restitution
  - Includes rotation
  - Includes friction
  - All at once



# 3. Collision resolution

- So we can resolve each contact
- But solving one may make another worse
- Could solve simultaneously
    - Build a massive LCP matrix
    - But not in real-time
- Instead, iterate over contacts repeatedly
    - Converge on global solution
    - Can balance computation time against accuracy

# Putting it all together

- Every frame:
  - All bodies are moved simultaneously
  - Pairs of potentially colliding bodies are detected
  - Detailed contact information is generated
  - The collision resolver is run
    - Velocities are updated
    - Penetration is removed
  - All bodies are drawn at their new positions

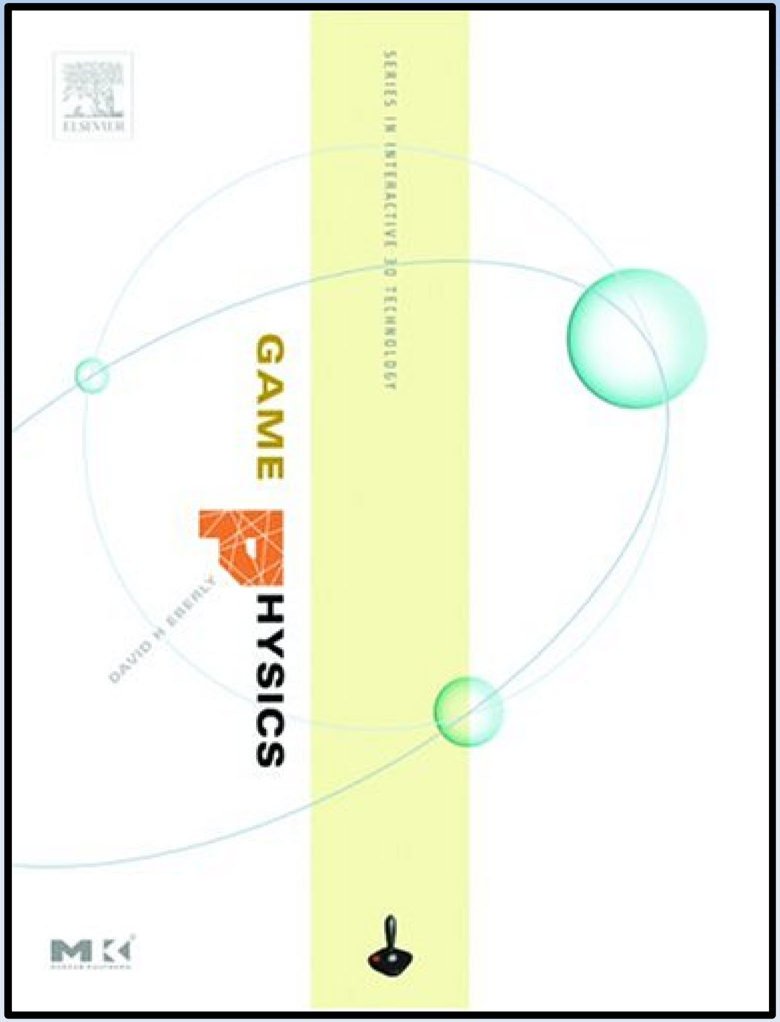
# Creating a physics engine

- Do you hate yourself?
- Do you have several years of your life to spare?
- Requirements:
  - Excellent maths skills
  - Excellent programming skills
  - Excellent patience
- Incredibly rewarding
  - Eventually

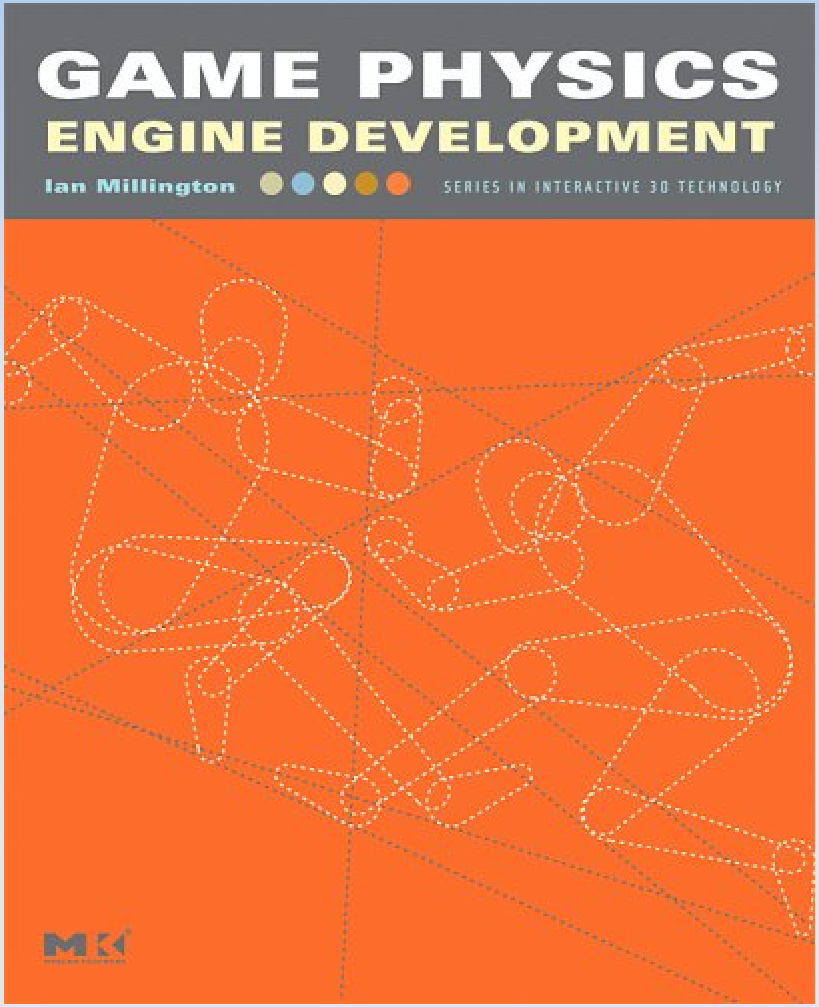
# References

*Real-Time Collision Detection*
Christer Ericson

# References



*Game Physics*
David Eberly



*Game Physics Engine Development*
Ian Millington

# Online resources

- Erin Catto
  - http://www.gphysics.com/
  - Box2D Lite: http://box2d.org/
- Glenn Fiedler
  - http://www.gaffer.org/game-physics
- Chris Hecker
  - http://chrishecker.com/Rigid_Body_Dynamics
- Thomas Jakobsen
  - http://www.teknikus.dk/tj/gdc2001.htm

# 2D physics engines

- Box2D
  - http://www.box2d.org/
- Chipmunk
  - http://wiki.slembcke.net/main/published/Chipmunk
- Farseer
  - http://www.codeplex.com/FarseerPhysics
- Large Polygon Collider
  - http://www.draknek.org/physics/

# 3D physics engines

- Bullet
  - http://www.bulletphysics.com/
- Open Dynamics Engine
  - http://www.ode.org/
- Havok
  - http://www.havok.com/tryhavok
- Large Polygon Collider
  - http://www.draknek.org/physics/ (awful)

# Questions?

# P.S. come to my other talk

**Learning through failure**
Why you're not making enough games

Warwick Game Design
S0.28, Social Studies
6:00 PM today