Game Technology

Lecture 9 – 12.12.2014
Physics 2

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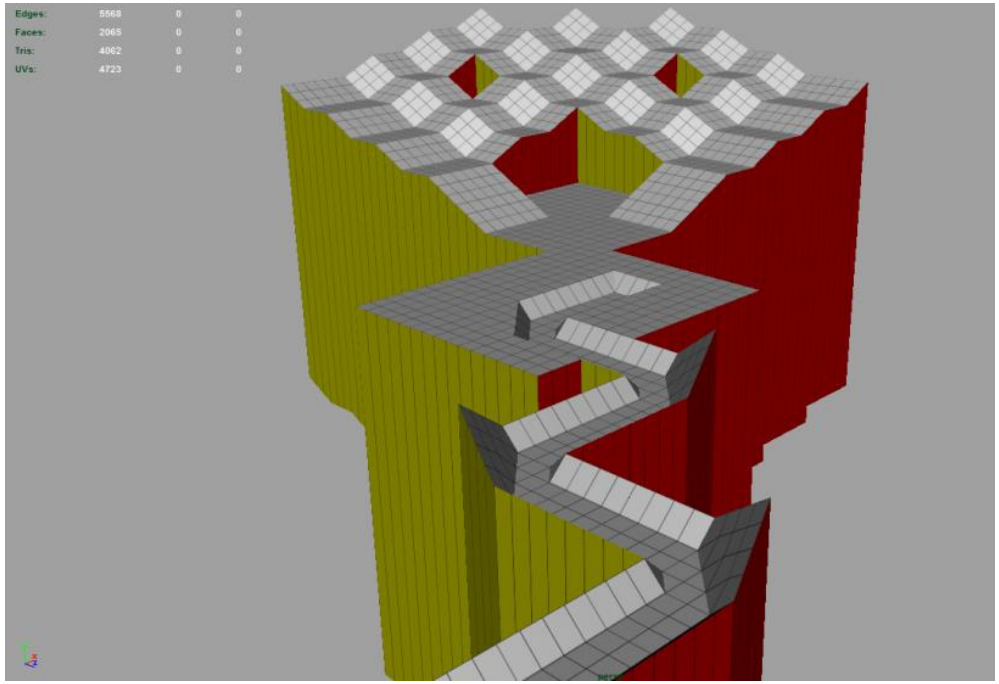

Dr.-Ing. Florian Mehm
Dipl-Inf. Robert Konrad

Prof. Dr.-Ing. Ralf Steinmetz
KOM - Multimedia Communications Lab

Preliminary timetable

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Lecture No.	Date	Topic
1	17.10.2014	Basic Input & Output
2	24.10.2014	Timing & Basic Game Mechanics
3	31.10.2014	Software Rendering 1
4	07.11.2014	Software Rendering 2
5	14.11.2014	Basic Hardware Rendering
6	21.11.2014	Animations
7	28.11.2014	Physically-based Rendering
8	05.12.2014	Physics 1
9	**12.12.2014**	**Physics 2**
10	19.12.2014	Procedural Content Generation
11	16.01.2015	Compression & Streaming
12	23.01.2015	Multiplayer
13	30.01.2015	Audio
14	06.02.2015	Scripting
15	13.02.2015	AI

Announcement

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Game Jams

- Game development contest
  - Vague theme (e.g. “10 seconds”)
  - Tight time constraints (e.g. 48 h)
  - Starting from scratch (design, assets, code, …)
- No excuses – just submit something…

The Head Wizards Course, 2014

Ludum Dare 30 @ TUD, 2014

A Maze Thing, 2013

10 Seconds to Apocalypse, 2013

Global Game Jam 2015@TUD

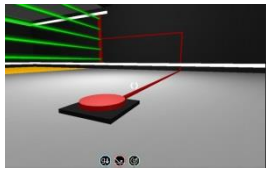
- Fr., 23.01.2015, 17:00 –
  So, 25.01.2015, 17:00
- Registration (first-come-first-serve):
  gamejam@kom.tu-darmstadt.de

10sion, 2013

10Up Experiments: Mountain Brew, 2014

The Most Important 10 Seconds Of Your Life, 2013

As We Are, 2014



Neon Multiverse, 2014

Announcement 2

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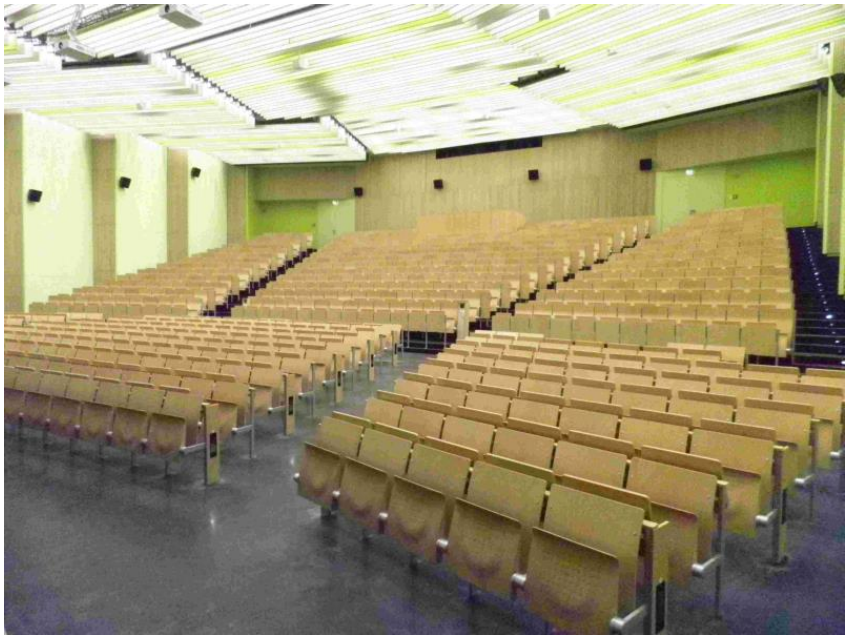
The exam is now scheduled for

Friday, 06. March 2015

09-11 AM

S101/A1



Adding Physics to Marbellous

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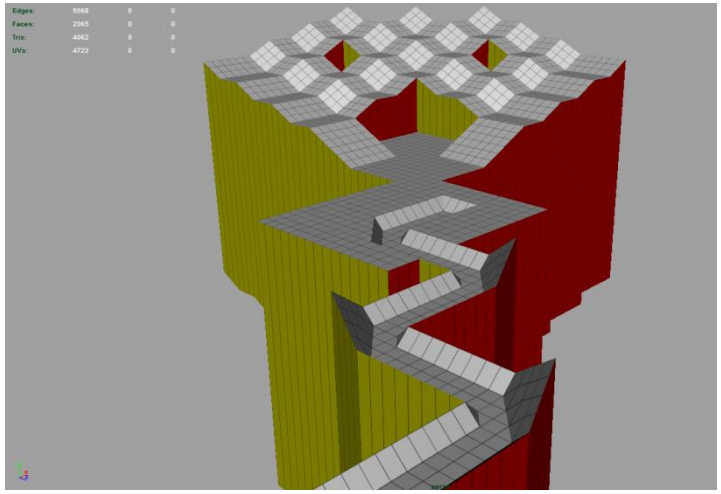
Collision with the level

- Level supplied by artist as 3D mesh
- How to handle the collisions with the mesh?



Friction

- Handle rotations
- Add friction

Controls

- Apply forces when keys are pressed

(Camera control

- Keep the ball in view
- Don‘t follow every single movement)

Hand-placed colliders

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Sometimes good placeholders for objects or level geometry

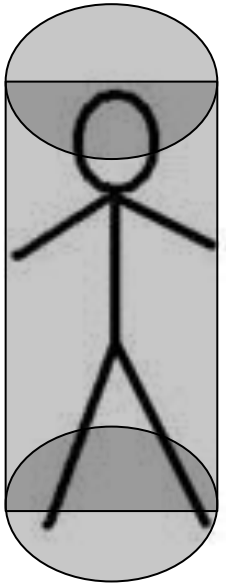
Planes

- Ground plane
- Simple intersection

Boxes

Spheres

Capsules



Height map

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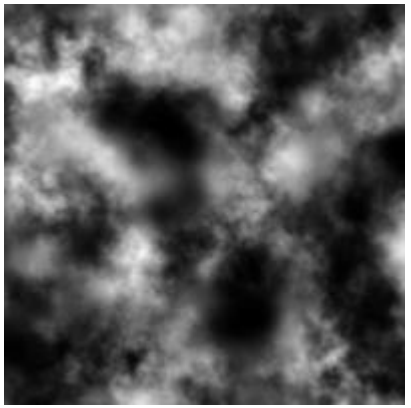
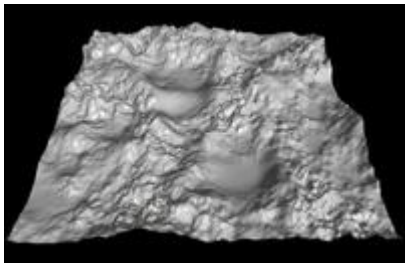
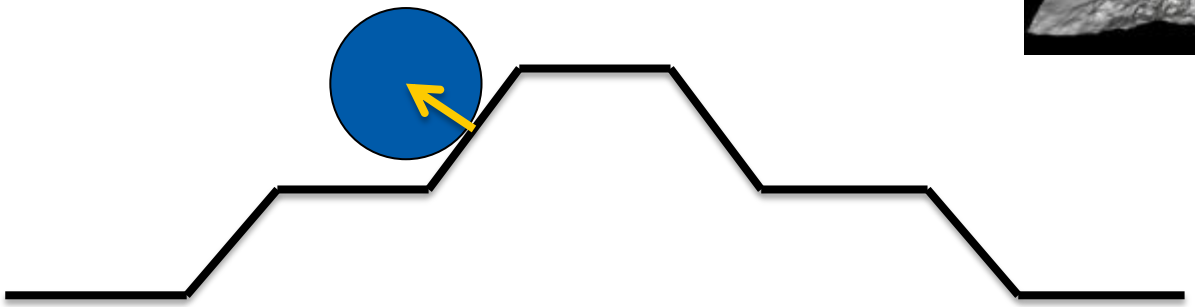
Supplied as a texture or generated

Gives height values at grid points

By interpolating, we can find the height of the mesh under the sphere and the normal







Using the mesh itself

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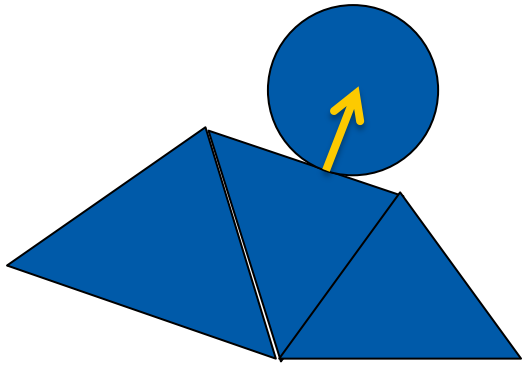
Intersection with triangles

Check all triangles

If sphere intersects a triangle, handle the collision



Using the mesh itself

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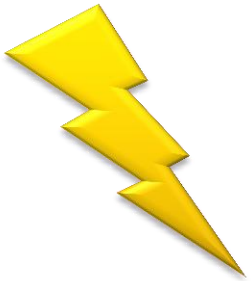
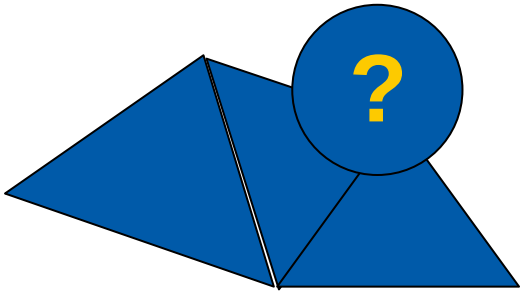


If there are multiple collisions

- Handle only one (most prominent)
- Handle all



Separating Axis Test

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If two objects are separated, there must be an axis which separates the two objects

- („Separating Axis Theorem“ → Not a theorem – follows from Hyperplane separation theorem by Hermann Minkowski)
- First mentioned in computer graphics in 1995

Separating Axis Test

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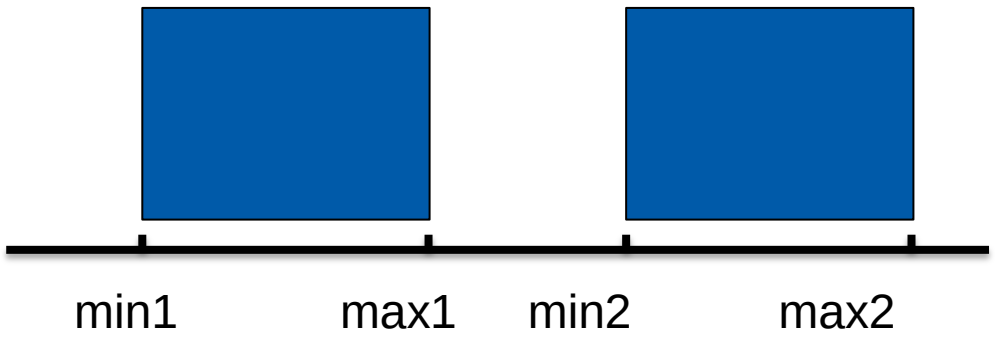
More exact

- There must be points P1 and P2 of objects 1 and 2 such that the normal resulting from P2 – P1 is a separating axis
- Separating Axis
  - Project all points of the objects onto the separating axis
  - We get the minimal and maximal points min1, min2 and max1, max2
  - The objects are separated iff max1 < min1 or max2 < min1



Separating Axis Test

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Infinite set of possible points to test for

It can be proven that an upper boundary exists

- Only the relevant axes have to be tested for
- If separation exists on any axis, the test is done → early out for positive test result
- If no separation exists, we still have to test all combinations of features → no early out for negative tests
  - Can be more efficient to reject the test based on other information, e.g. bounding boxes

For polygonal objects, the features are

- Faces
- Edges
- Vertices

Separating axes for spheres

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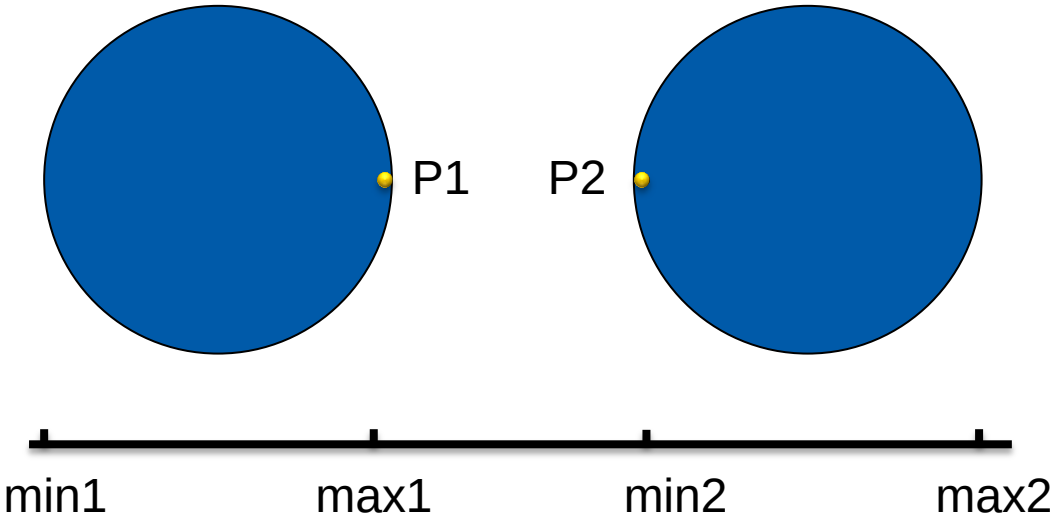
Spheres have no clear feature points

We have already used the separating axis test, though

- The relevant features for two spheres are the two closest points of the spheres
- We find them by finding the axis from one sphere‘s center to the other‘s center
- The intersection test in the previous lecture used this axis for testing intersections



Triangle-Sphere-Test

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Relevant Features of the Triangle

- Face (x1)
- Vertices (x3)
- Edges (x3)

Relevant feature of the sphere

- The point on the surface closest to the feature of the triangle

SAT: Testing the plane of the triangle

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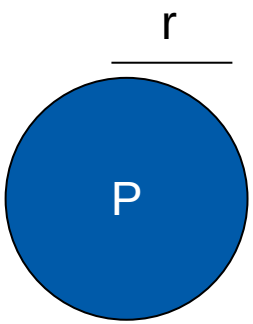
(We have done this test already – need to define the plane)

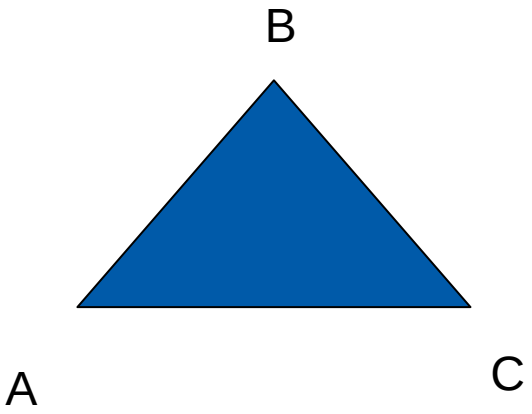
Normal: Use the cross product (very useful for finding normal vectors)

- n = normalize((B – A) x (C - A))



Distance

- Insert one of the points into the equation for distance
- n*A – d = 0 (since A lies on the plane of the triangle)
- →n*A = d



Test for separation

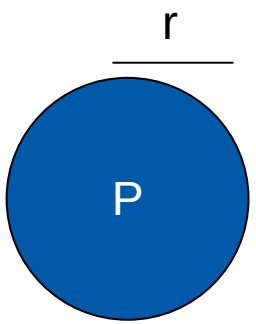
- Separation = distance(Plane, P) > r

SAT: Vertices

Here shown for A (similar for B and C)

Finding the sphere‘s feature

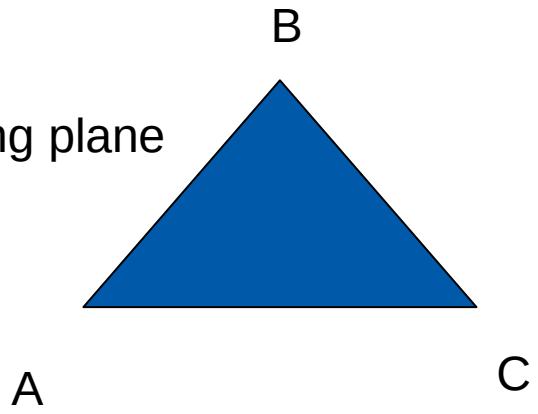
- Along the line from A to P



Compute distance from A to P

Separation (along this axis) iff

- Distance d > r
- And B and C lie on the opposite side of the separating plane



SAT: Vertices

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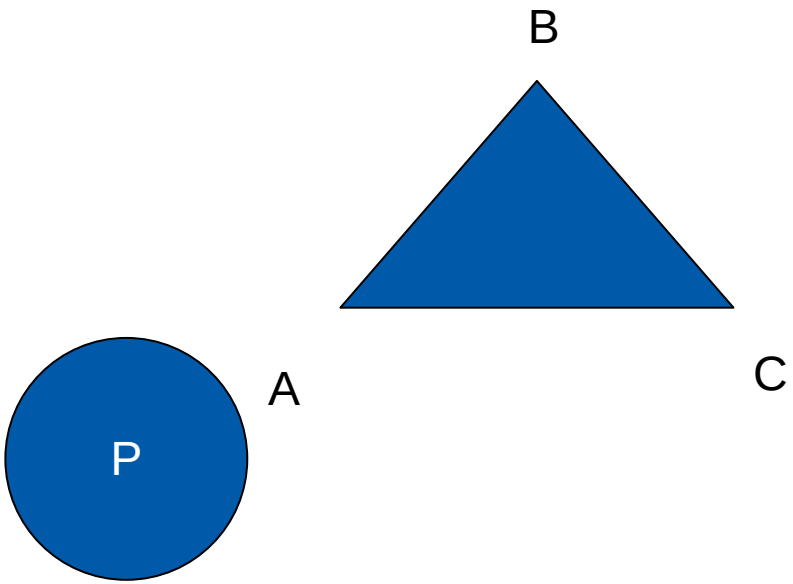

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TECHNISCHE UNIVERSITÄT DARMSTADT

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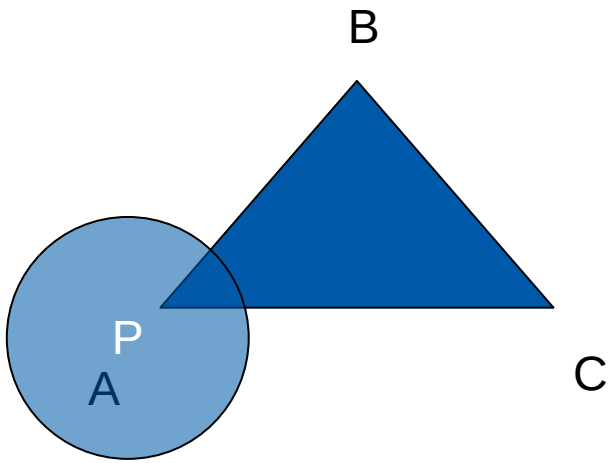

SAT: Vertices

TECHNISCHE UNIVERSITÄT DARMSTADT

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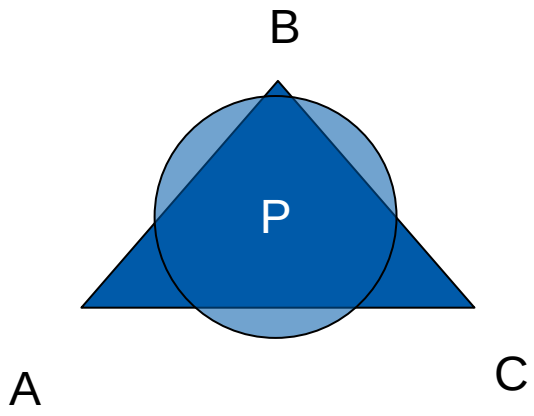

SAT: Vertices

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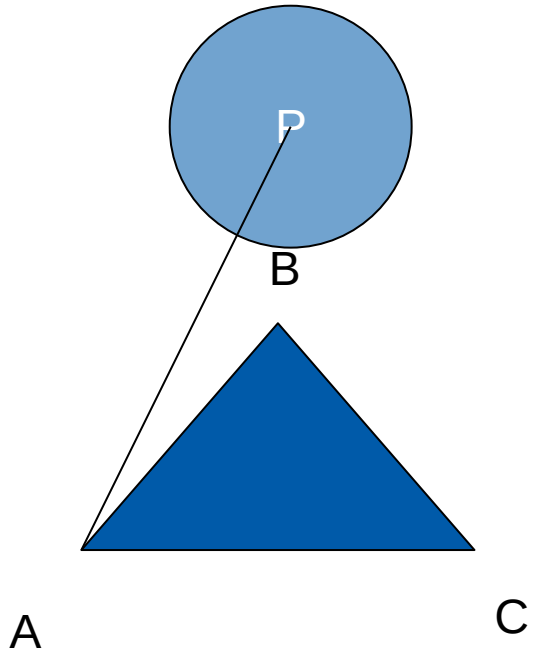
Separation (along this axis) iff

- Distance d > r
- And B and C lie on the opposite side of the plane

→ **We assume that A-P is the separating axis**

→ **No check if A is the closest point**

→ **B and C might be separating axes!**



SAT: Edges

Here shown: AB

Find a point for Q for which Q-P is a normal vector orthogonal to AB

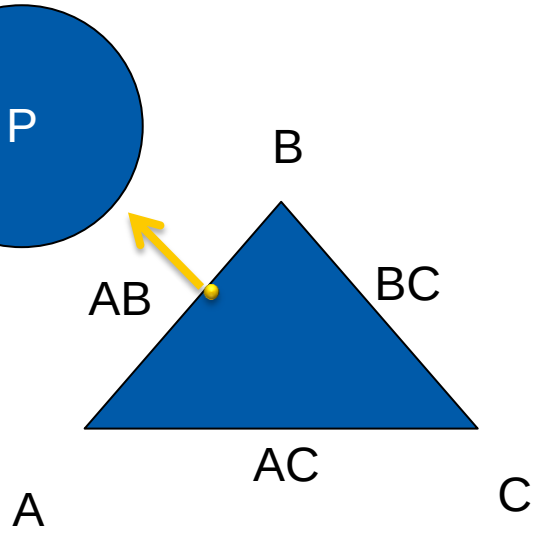
→ **Projection of P onto AB**

→ Use the dot product (ideal for projecting vectors onto each other)

Determine the distance d of Q to P

AB defines a separating axis iff

- Distance d > r
- C lies on the other side of the plane through AB with normal PQ



SAT: Edges

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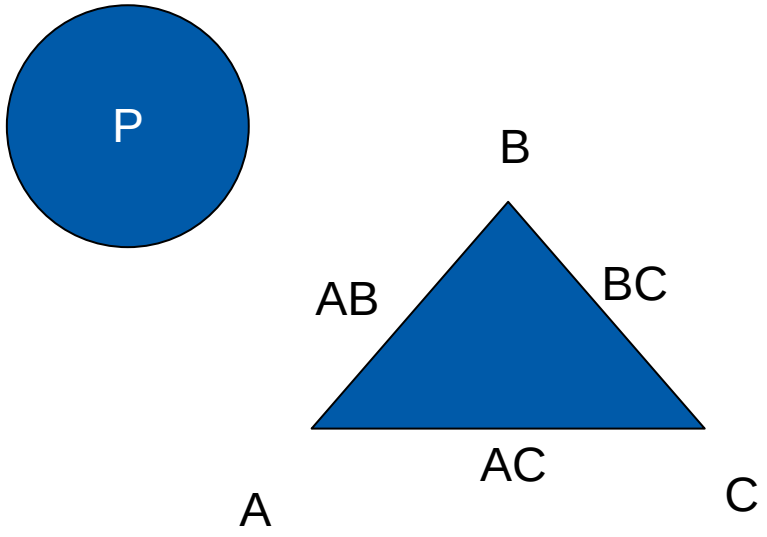

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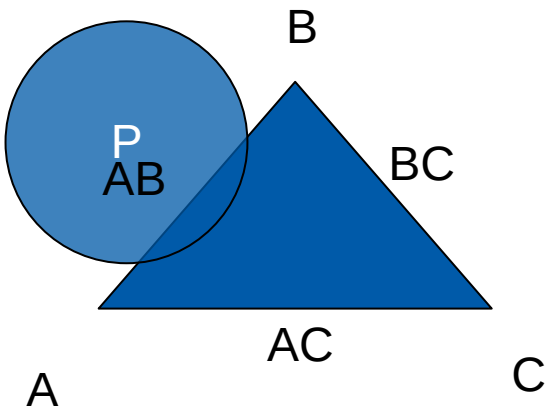

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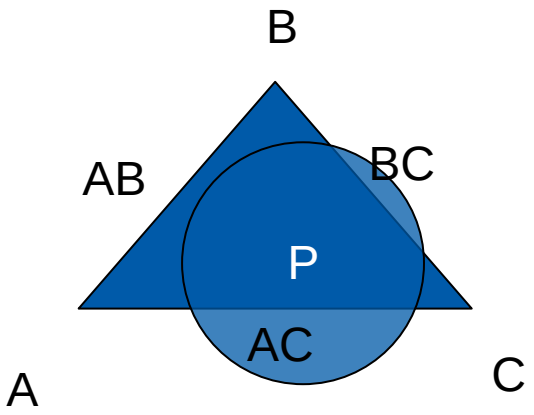

Speeding the calculation up

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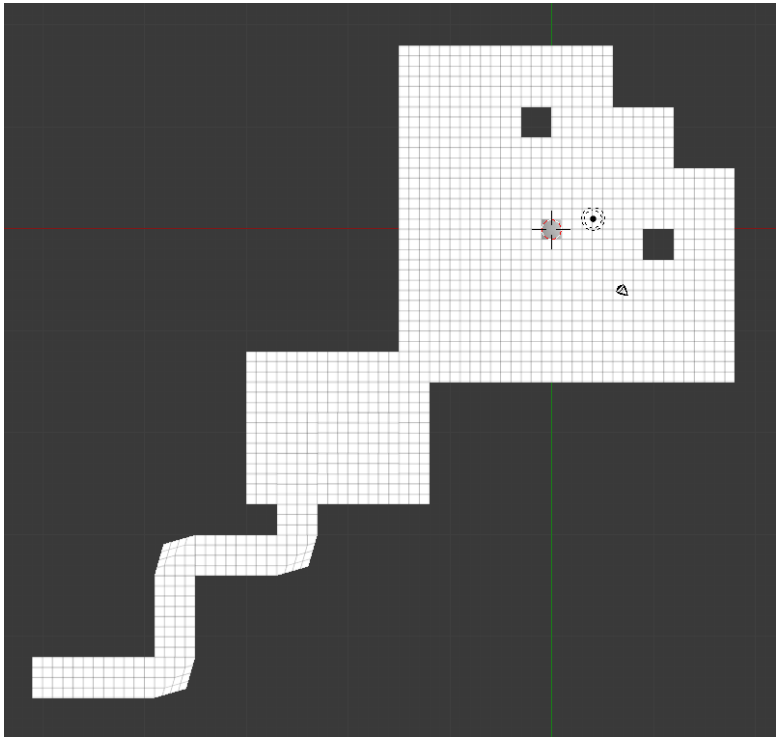
Note: In our case, the level is essentially 2D

- Most of our collisions will be from the top of the level

Use a space partition

- Regular Grid
- Quadtree
- KD-Tree
- BSP



Regular grid

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Subdivide space regularly

E.g. specify

- Cell size in units
- Start point

For each cell

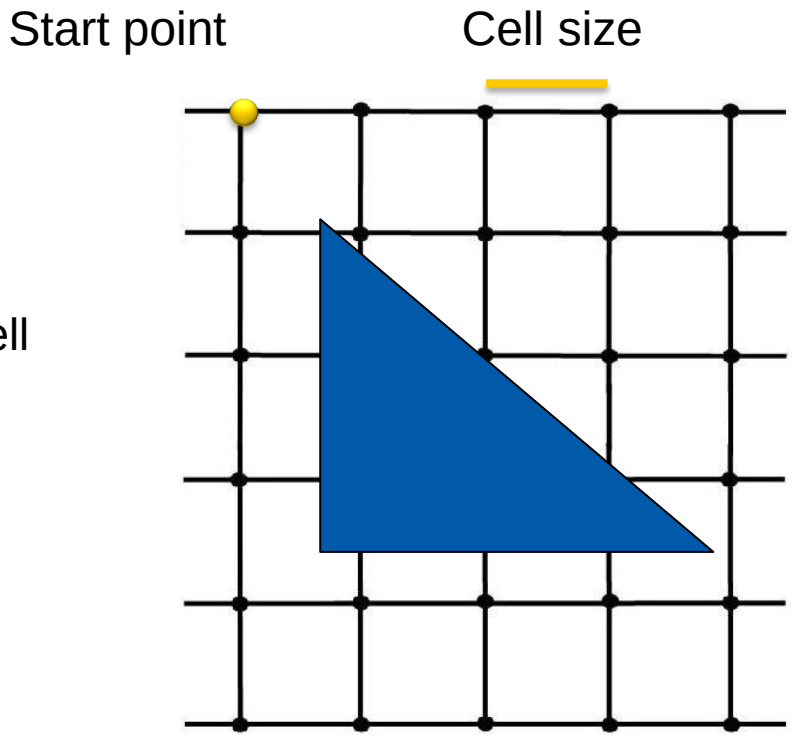
- Test if an object intersects (partly) with the cell
- If so, save a reference to this object
- (Objects can be in several cells)

Advantages

- Easy to compute
- Lookup of cells is trivial

Disadvantages

- Sparsity kills the performance
- Clusters



Quadtree(2D), Octree(3D)

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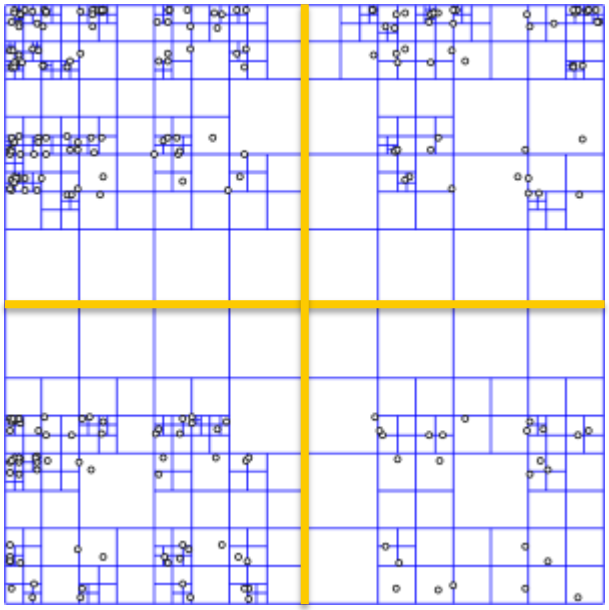
Start with a rectangular shape

Subdivide the space into 4 or 8 subdivisions of equal size if the number of contained objects is too large

Until the required minimal number of objects per subdivision is found



Advantages

- Still simple lookup where an object is placed
- Can handle clusters better

Disadvantages

- Can cope less with changing number and position of objects

KD-Tree

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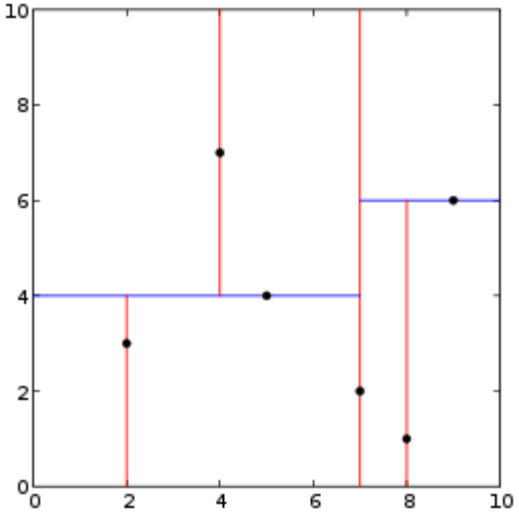
Similar idea to Quad/Octree

Subdivide starting from a rectangular shape

Choose the subdividing line

- E.g. median point of the contained objects (cutting them in half)

Alternate axes for subdivision



Advantages:

- Well suited for clusters

Disadvantages

- Lookup harder than octree

Binary Space Partition

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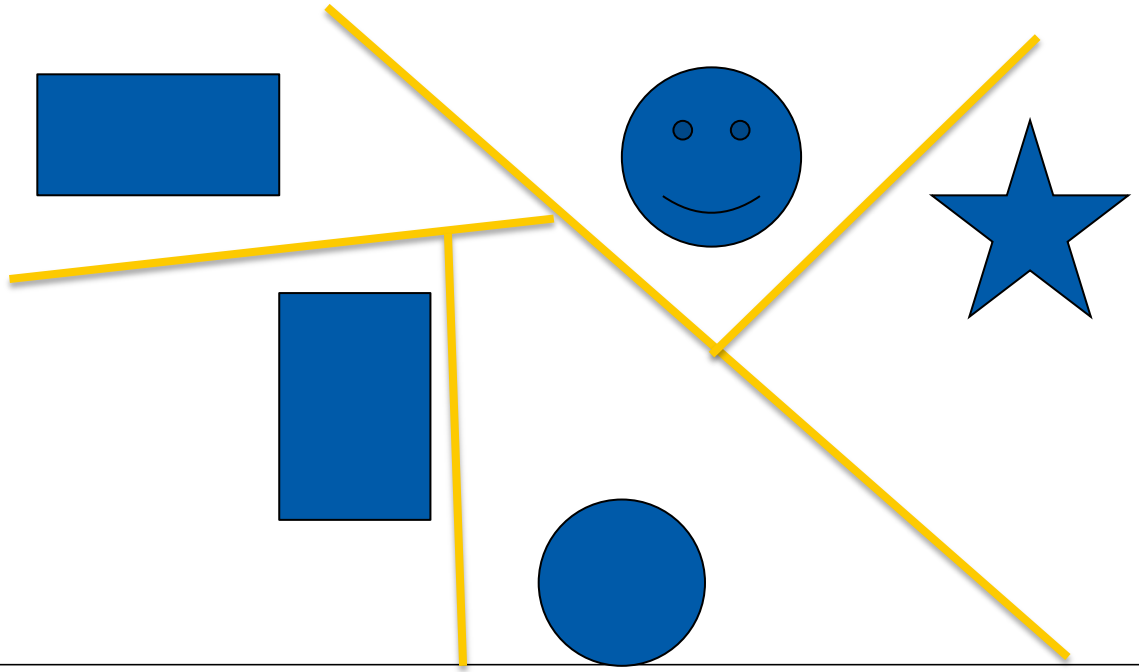
Generalization of KD-Tree

Subdivide the space into half-spaces with arbitrary planes

Used previously to speed up rendering (Quake Engine)



Reducing the dimensionality

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Many problems in 3D games are essentially 2D

- Heightmaps
- Top-down shooters
- Real-Time Strategy games
- ...

In Marbellous, we can expect that

- No overhangs are present in the level
- The sphere will stay close to the mesh at all times

If we look at the level from above, we can see that if we put a grid over the game world, only the triangles in the same 2D cell can be possibly colliding

→ During initial setup and the lookup, project everything into 2D

Lookup

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Saving the triangles

- We should save only the triangles that are contained in the grid cell
- → We need to check intersection between a rectangle and a triangle

Minimizing storage

- Re-use the vertex and index buffer
- Save only the index of the triangle
  - (Ideally, we will not suffer from too many cache misses, since the goal in the first place is to reject most collision tests early)

Intersection between the triangles and the grid

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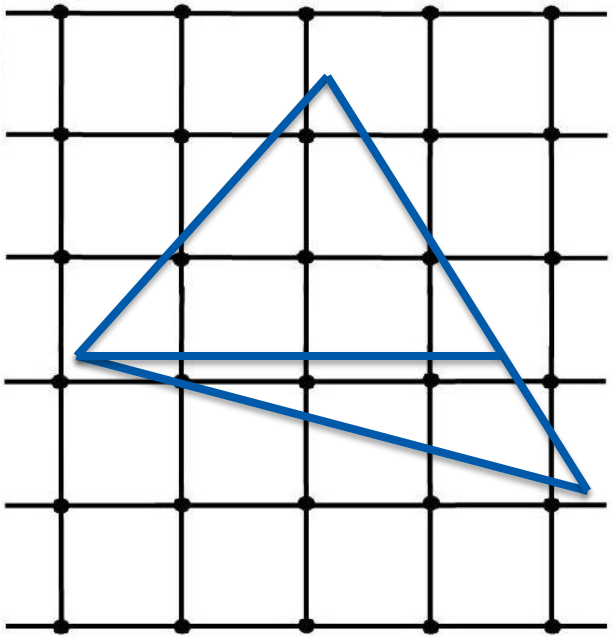
Re-use the scanline rasterization algorithm

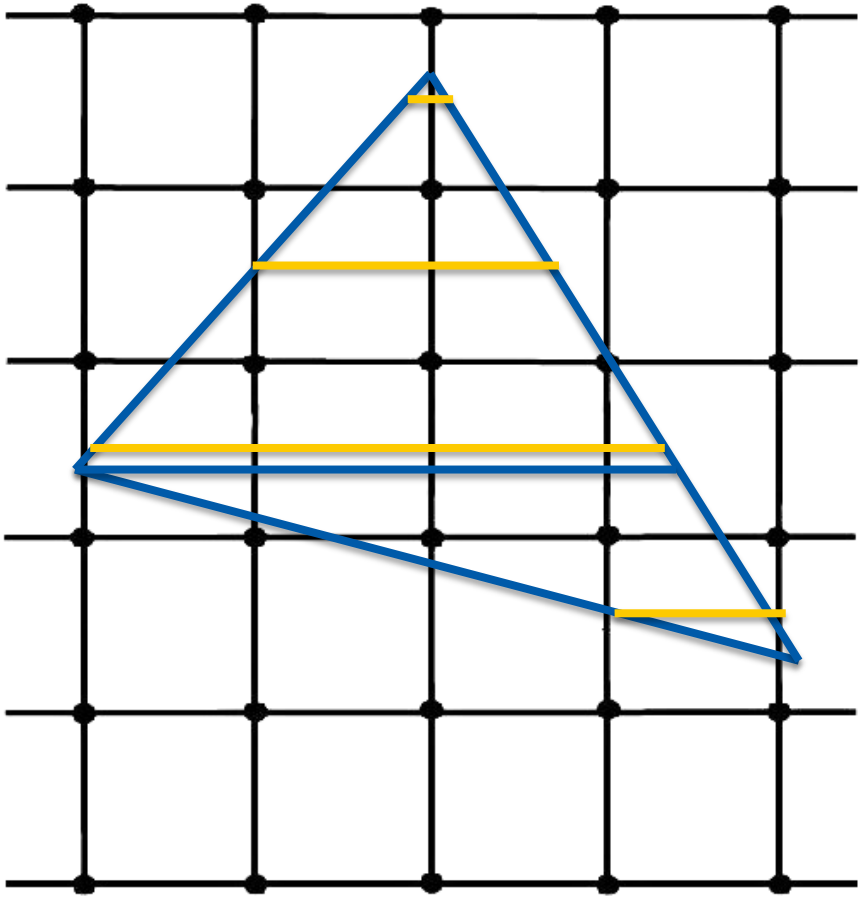
- Very similar task
- But have to watch out due to larger cell size

Original algorithm

- Find edge longest with biggest ydif
- Fill lines between long edge and other edge 1
- Fill lines between long edge and other edge 2



Triangle Rasterisation



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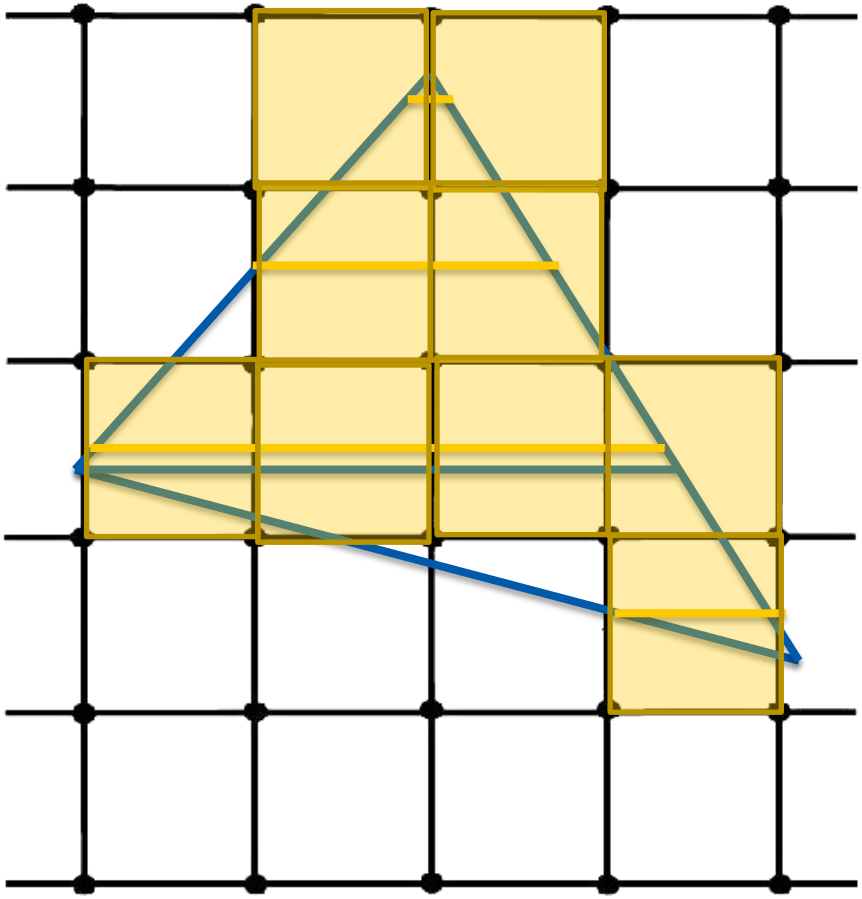

New algorithm

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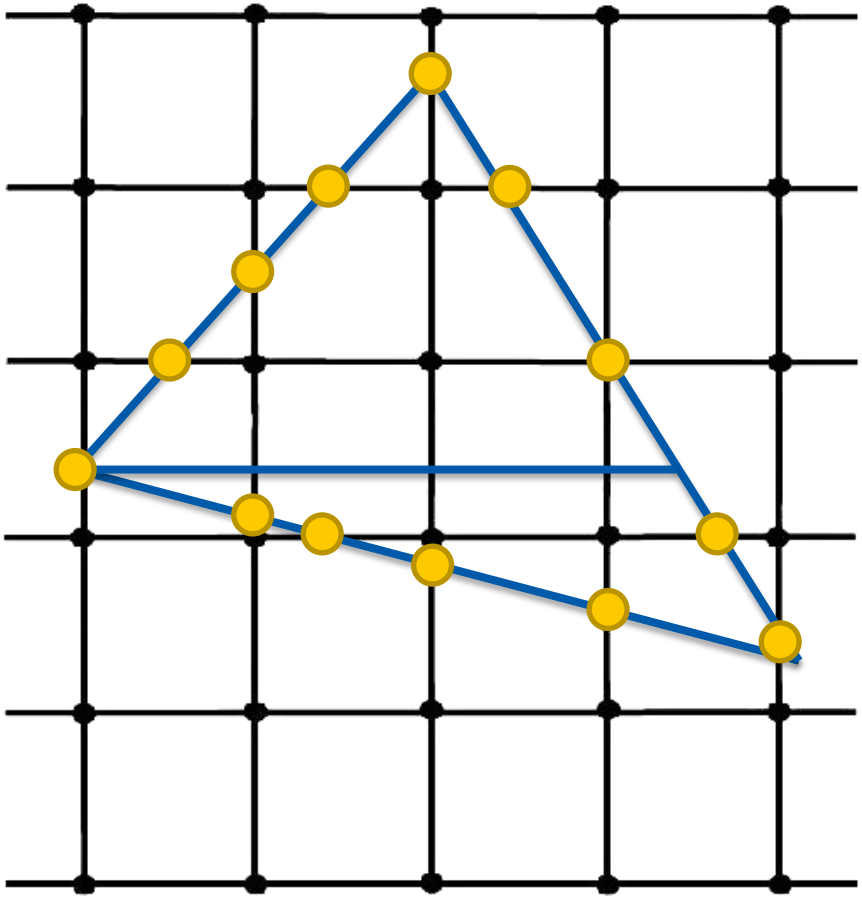
Calculate intersection with all grid lines

For each row

- Left extent is the minimal intersection point
- Right extent is the maximal intersection point

Triangle Rasterisation



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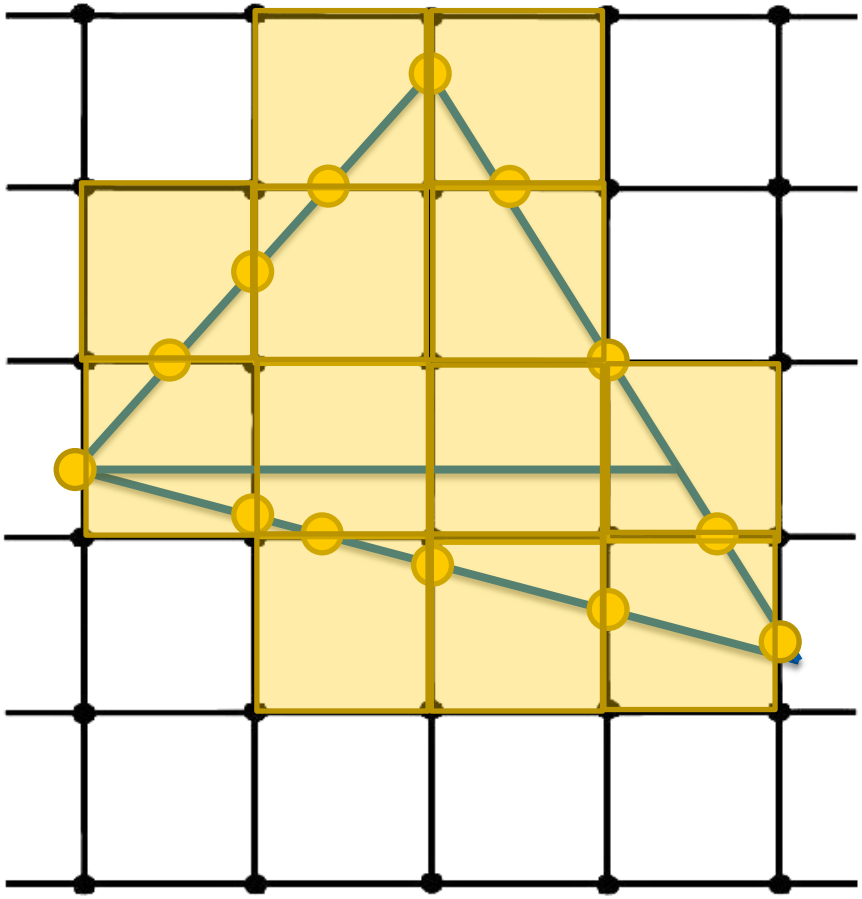

Intersection between the sphere and the grid

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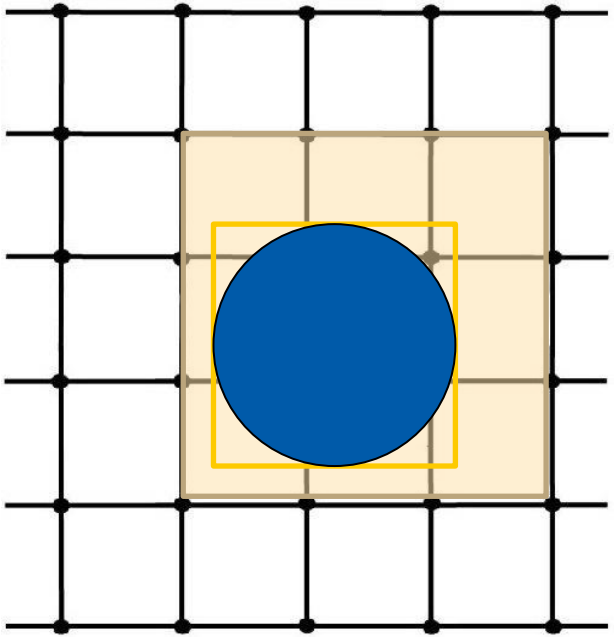
- Use the bounding box of the sphere
- Defined by the extents in the x-z-Plane
- (Or implement rectangle-sphere intersection)



Is it worth it?

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No (at least not for our exercise)

On a Core2 Duo @2.7 GHz, the intersection with the mesh takes about 0.908 ms in Release mode

But, for production code, larger meshes and more objects, it could become relevant

(Triangle-Sphere Intersection implemented with optimized code by Christer Ericson, http://realtimecollisiondetection.net/blog/?p=103)

Broad Phase vs. Narrow Phase

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Broad Phase

Rule out as many possible collisions

Only call narrow phase if separation can not be proven here

Reduce the problem

- Use spatial data structures (grid, octree, etc.)
- Use bounding volumes (and bounding volume hierarchies)

Narrow Phase

Check for exact collisions

Use exact tests

- E.g. based on SAT

Should be much slower than broad phase and therefore seldomly called

Provide collision data to resolver

Time Handling

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Fixed Time Step

- Explicit Time Step → Our method
- (Semi-)Implicit Time Step Method
  - Try to predict the times of collisions and handle them at the beginning

Adaptive Time Step

- Retroactive Detection
  - If there is interpenetration at t +deltaT, use deltaT *= 0.5 and retry
- Conservative Advancement
  - Predict the next time of collision
  - Advance to this time

Continuous Collision Detection

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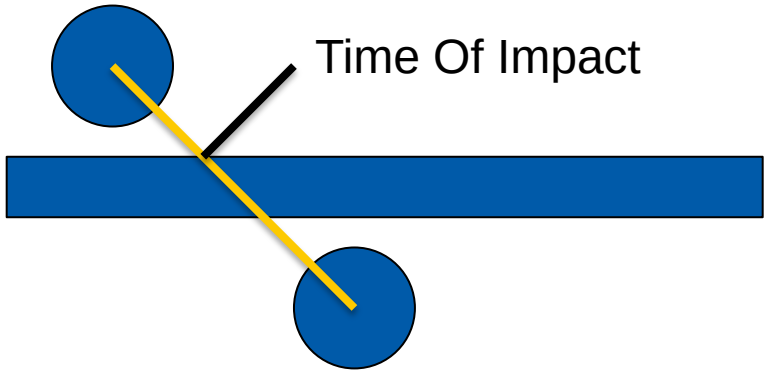
Check if an object moved through another in the frame

- On one side before, on one side after
- Swept shape algorithms

Time of impact ordering

Go to time of impact, resolve there



Speculative Contact

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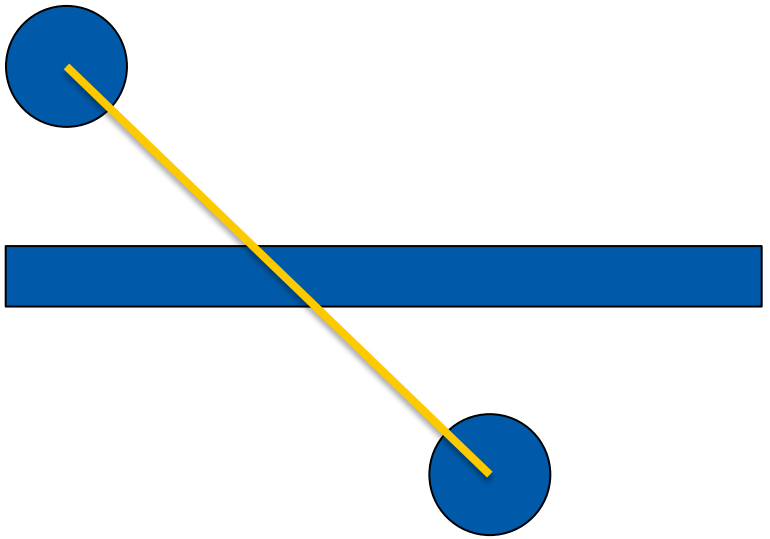
Calculate the distance to the collider

Remove just enough velocity so they touch in the next frame



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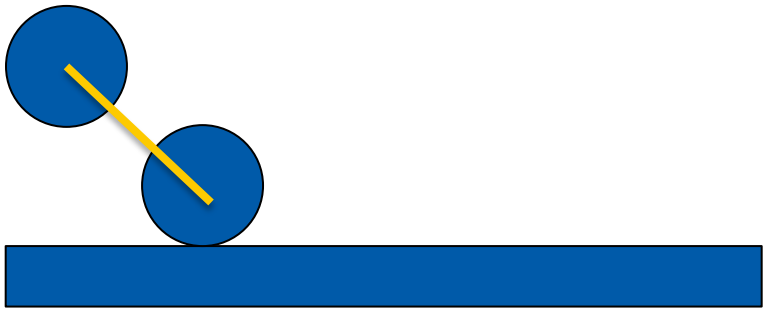

Constraints

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Stiff constraints

- Keep objects at an exact length compared to each other
- E.g. when attached to a steel cable

Springs

- Variable length between objects
- E.g. when attached to a bungee rope

Stiff Constraints - Rods

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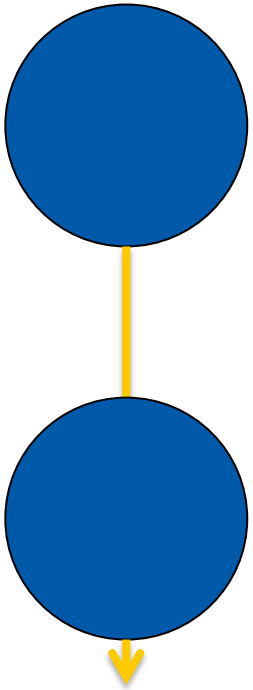
Distance between two objects is determined to stay constant

→ **Separating Velocity between the two objects along the vector from one to the other should be 0 at all times**



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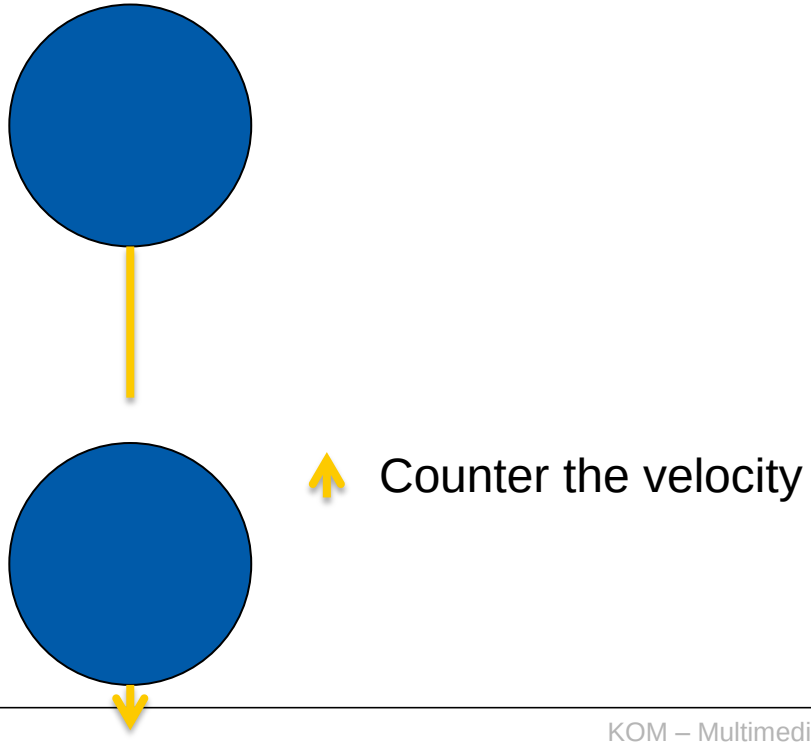

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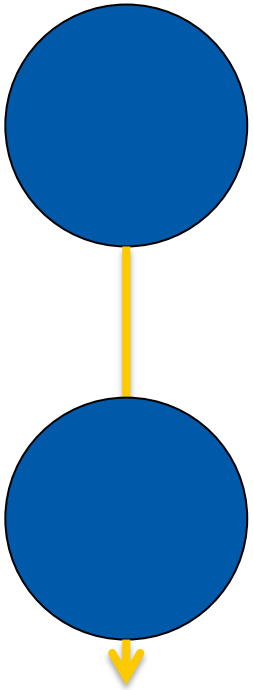

Spring Constraints

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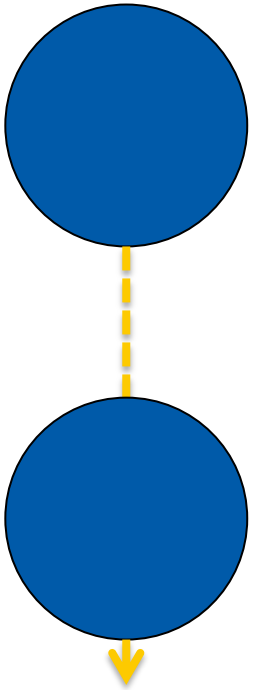
Model a spring between two objects (one might be stationary)

Spring force

- Rest length (no force)
- Stiffness
- (Breaking point)



Hooke‘s Law

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F = -k * (l – l0)

F: Spring force

k: Spring constant (stiffness)

l: Current length of the spring

l0: Rest length of the spring

Apply the resulting force to the objects that are attached

(One might be immovable)

Stiffness

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Also a property of numerical systems

The stiffer, the more problems we face → exploding systems

J. D. Lambert : "If a numerical method with a finite region of absolute stability, applied to a system with any initial conditions, is forced to use in a certain interval of integration a steplength which is excessively small in relation to the smoothness of the exact solution in that interval, then the system is said to be stiff in that interval."

Particle networks

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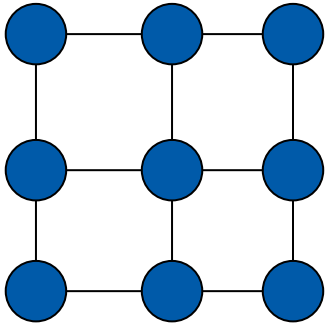
Connect multiple particles with springs

Approximation for deformable objects

Often used for cloth

Problems/Challenges

- Stiff constraints
- Self-intersections
- Stability



Deformable objects

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Generalization of particle networks

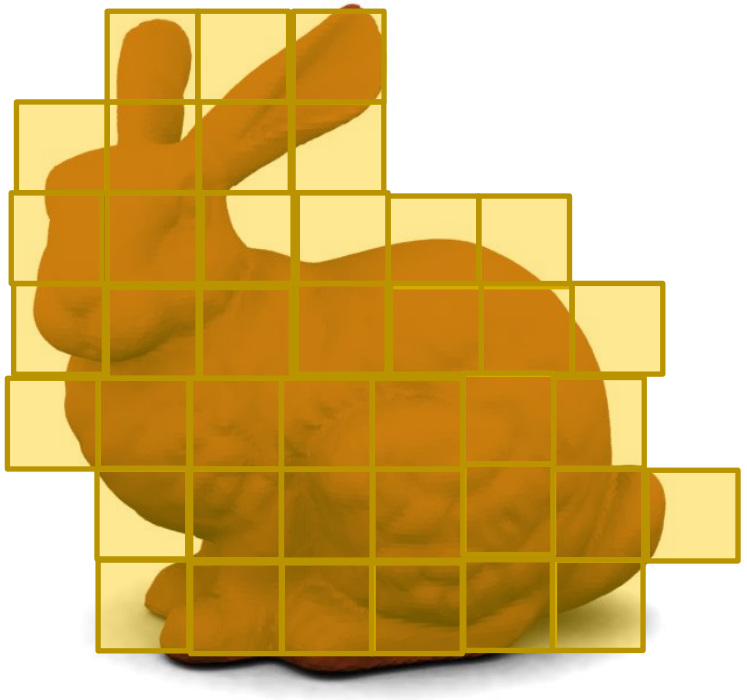
Finite Element Method from Mechanics

Model forces inside the object

- Stress
- Strain

Gasses, Liquids

- Discretize into a vector field
- Calculate flow by solving the Navier-Stokes-Equations



Collision handling schemes

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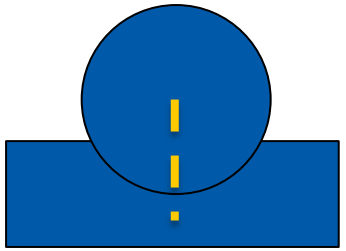
Impulse-based Micro-Collisions

- What we are using

Spring-Based

- Insert a spring at the point where the collision is detected
- Forces the objects out again



Constraint-Based

- Formulate the collisions as violations of constraints

Sequential Impulses

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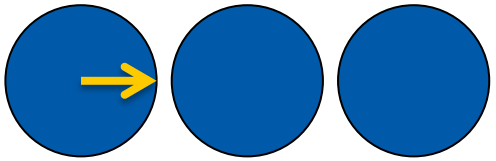
Aka. Propagating Impulses

Stability

- Add iterations
- Solve impulses in order of importance



Adaptive schemes

- Few, „large“ contacts → need fewer iterations
- Many contacts → need more iterations

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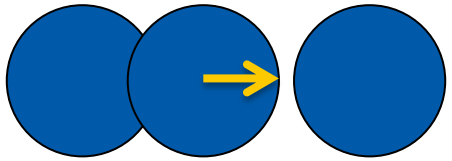

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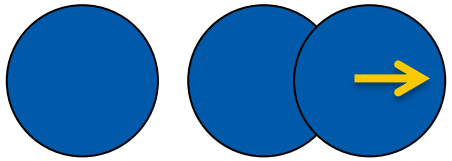

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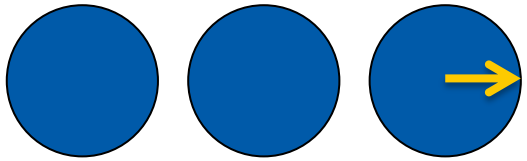

Adaptive schemes

- Few, „large“ contacts → need fewer iterations
- Many contacts → need more iterations

Constraint-based

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Constraint Vector

- For each collision or constraint
- Equality constraint
  - Objects should stay at a fixed relative position
- Inequality constraints
  - E.g. for separating objects after collisions

For each collision, add a constraint to the constraint vector

Results in a large system of equations

Solve via Linear Complementarity Problem (LCP)

Other integrators

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Runge Kutta 4th order (RK 4)

- Approximate from 4 values

$$y_{n+1} = y_n + \frac{h}{6}(k_1 + 2k_2 + 2k_3 + k_4)$$
$$t_{n+1} = t_n + h$$

$$k_1 = f(t_n, y_n),$$
$$k_2 = f(t_n + \tfrac{h}{2}, y_n + \tfrac{1}{2}k_1 h),$$
$$k_3 = f(t_n + \tfrac{h}{2}, y_n + \tfrac{1}{2}k_2 h),$$
$$k_4 = f(t_n + h, y_n + k_3 h).$$

Velocity-less Verlet integration

- Uses no explicitly saved velocity
- Instead, uses position difference between this and previous calculation

- x(t + deltaT) = 2 * x(t) – x(t – deltaT) + deltaT^2 * a

Rotation

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Angular Velocity, Acceleration

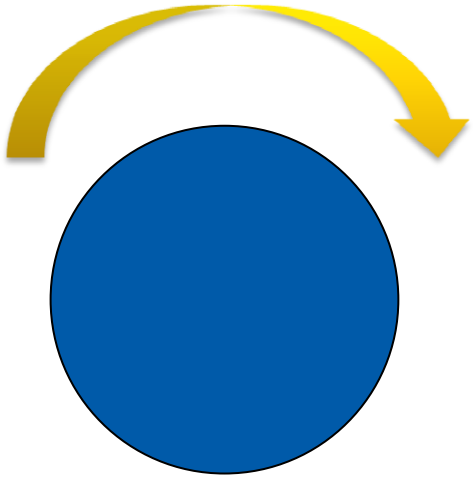
- Save as additional properties
- Velocity: 3-Vector, Rotations around x, y, z axis
- Accelaration: Change in angular velocity

Mass Moment of Inertia

- Property that resists the change in angular velocity

Torque

- Force acting off-center



Torque

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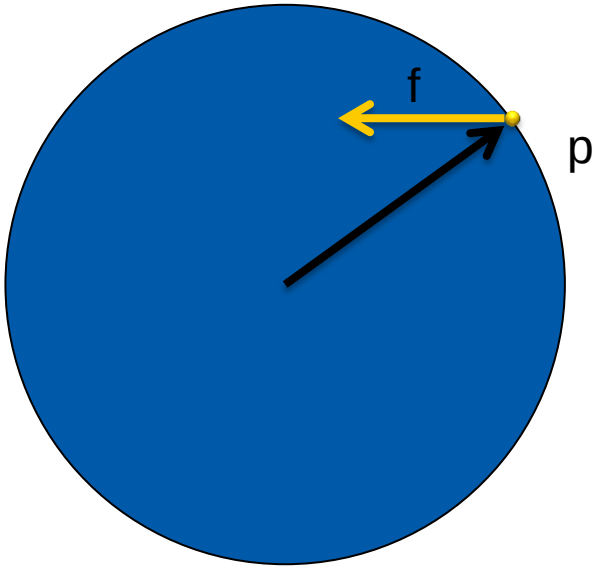
torque = p x f

p is the point of application

f is the force applied

Note: If p and f are in the same direction

→ No torque



Mass Moment of Inertia

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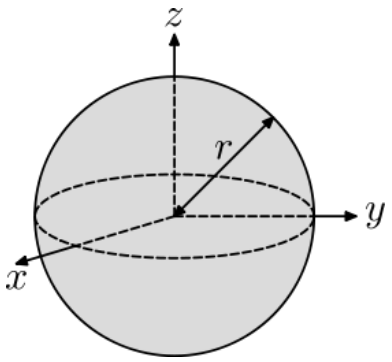
Inertia Tensor – Generalized version of a matrix

For purposes of games, most often 3x3

Diagonal Matrix for moments of inertia about x, y, z-axis
Off-center entries encode product of inertia

See http://en.wikipedia.org/wiki/List_of_moments_of_inertia



$$I = \begin{bmatrix} \frac{2}{5}mr^2 & 0 & 0 \\ 0 & \frac{2}{5}mr^2 & 0 \\ 0 & 0 & \frac{2}{5}mr^2 \end{bmatrix}$$

Inverse Inertia Tensor

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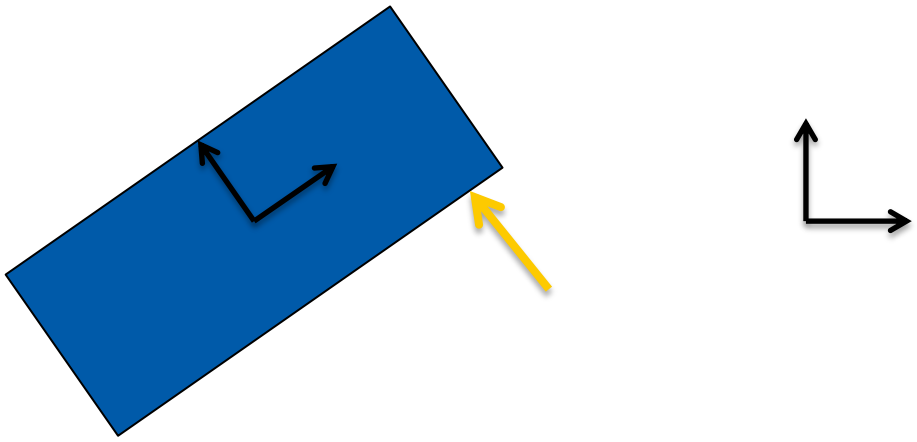
Remember the calculation of forces

F = m * a → a = F / m

We need the inverse of the inertia tensor for the equivalent formula

Additionally, need to transform to the world coordinate system

→ Torques given in world coordinates



Integration

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Add an accumulator for Torque
(D‘Alambert‘s Principle also works here)

Add all forces to linear accumulator

Calculate torque for each force

Add torques to torque accumulator

Integration

- Multiply inverse mass moment of inertia with sum of torques

Handling non-spherical rigid bodies

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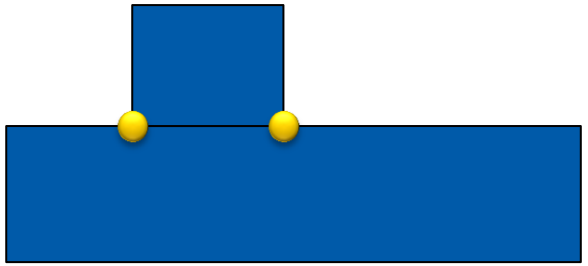
E.g. a box

Can collide with any feature

- Face
- Vertex
- Edge



If we handle only one feature, the others would sink

Sequential impulses

- One part starts sinking into the floor
- Push up → Rotation
- Continue
- Needs iterations to get stable

Handling non-spherical rigid bodies

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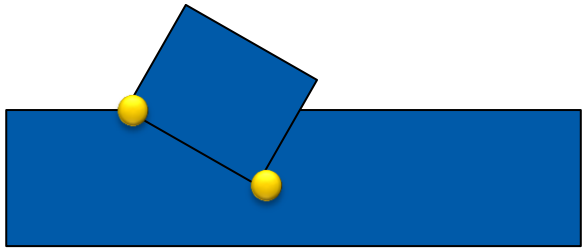

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Sequential impulses

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Friction

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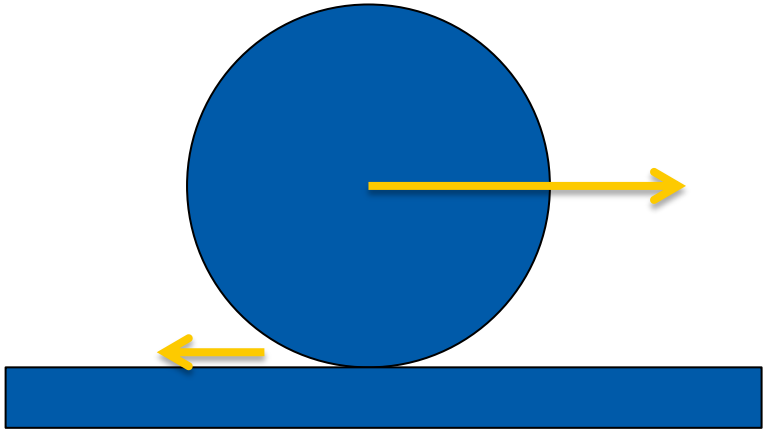
In the previous exercise, our spheres slided over the floor

→No rotation

→They came to rest because of dampening and not friction

Friction resists the spheres at the point of contact with the floor

- Rolling along the floor
- Different coefficients
  - Ice
  - Smooth floor
  - Sand
  - …



Coulomb‘s Law

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Depends on

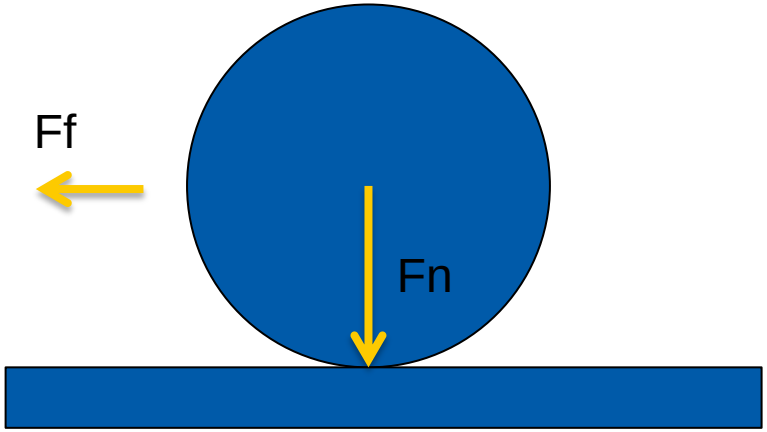
- normal force that presses the surfaces together
- coefficient of friction
  - Most dry materials have a coefficient of friction of 0.1 to 0.6

Ff: Friction force

μ: Coefficient of friction

Fn: Normal force

$$F_\mathrm{f} \leq \mu F_\mathrm{n}$$



In 3D

- Tangential plane
- Force lies in this plane

Friction

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Static friction

- Keeps objects in place
- Start moving when the limit is overcome
- f_static <= k_static * |r|
- k_static: Constant for friction between the involved materials
- r: Reaction force of the ground at the point of contact

Dynamic friction

- Force between the objects while they are sliding across
- f_dynamic = -v_planar * k_dynamic * |r|
- v_planar: The velocity of the object across the surface
- k_dynamic: Constant for dynamic friction

Contact basis

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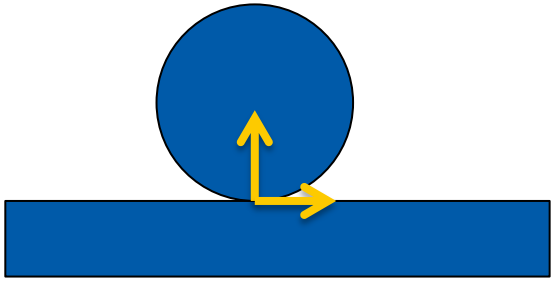
Calculating friction requires us to calculate the velocity along the contact

Handle collision with a collision basis

3 orthonormal vectors

- x: collision normal
- y, z: Perpendicular to x, define the plane of the contact



Calculating the contact basis

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x: Contact normal

y: Choose a vector perpendicular to x

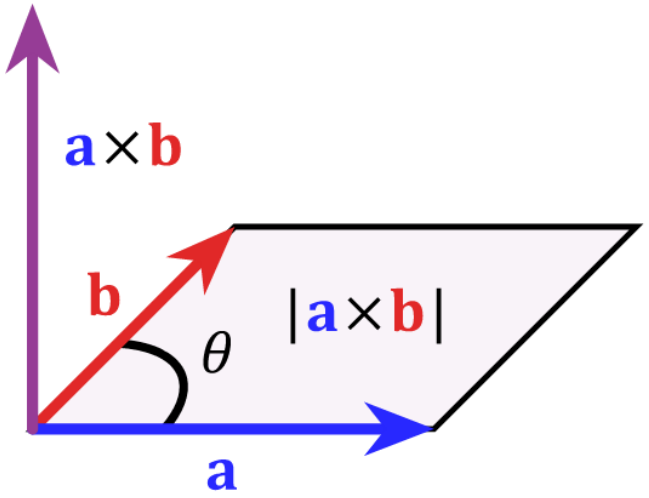
Cross product: A x B is perpendicular to A and B (unless they are parallel)

Use an axis, e.g. global z

y = x x (0, 0, 1)

Choose third vector to be perpendicular to x and y

z = x x y



Velocity resolution

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Find contact basis

Calculate the change in velocity of the contact paint per unit impulse

Invert this to get a way to counter velocities

Calculate the x-term of the impulse (along the collision normal – our old calculation)

Calculate the y and z-terms of the impulse (for friction)

Apply the impulse

Velocity resolution

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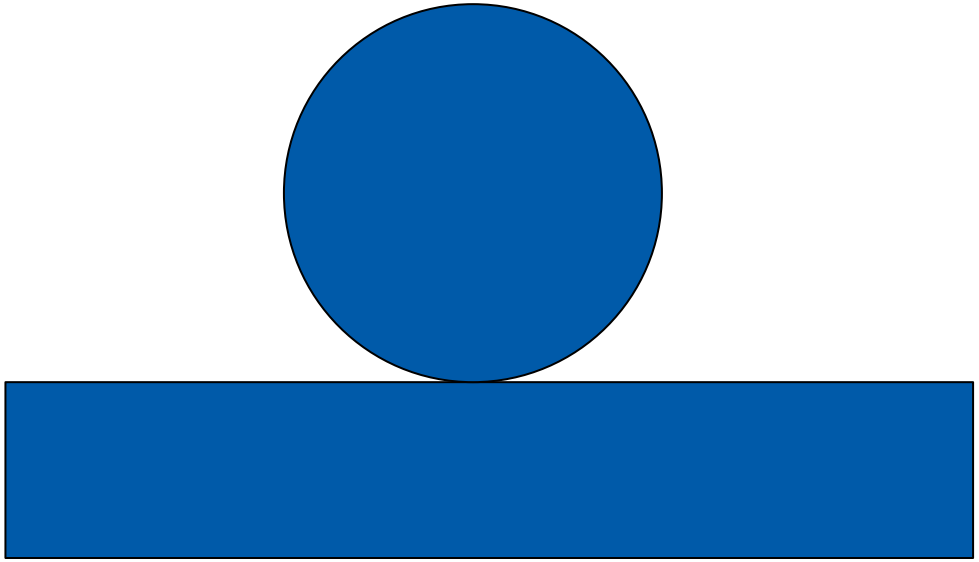
Find the collision collision normal and point of collision



Velocity resolution

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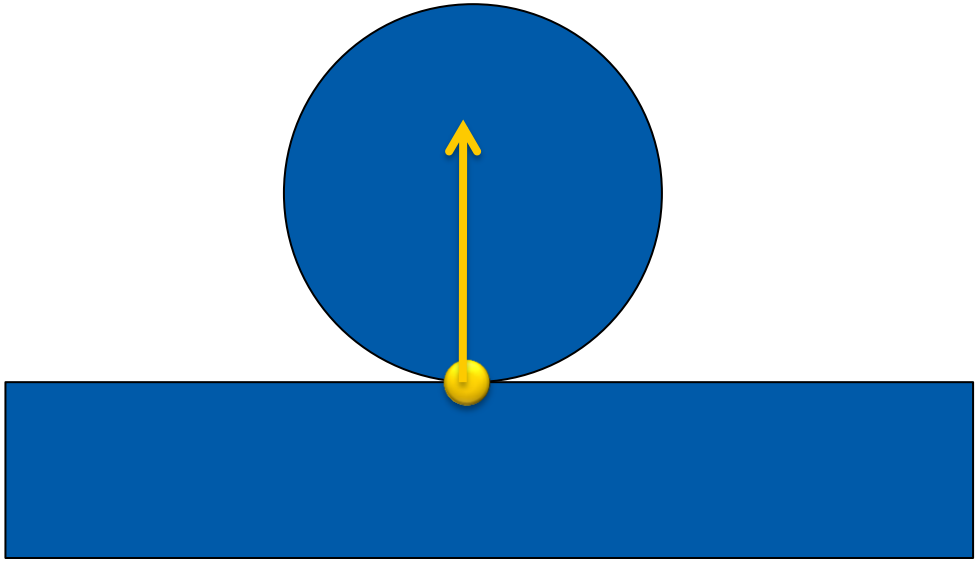
Find the collision collision normal and point of collision



Velocity resolution

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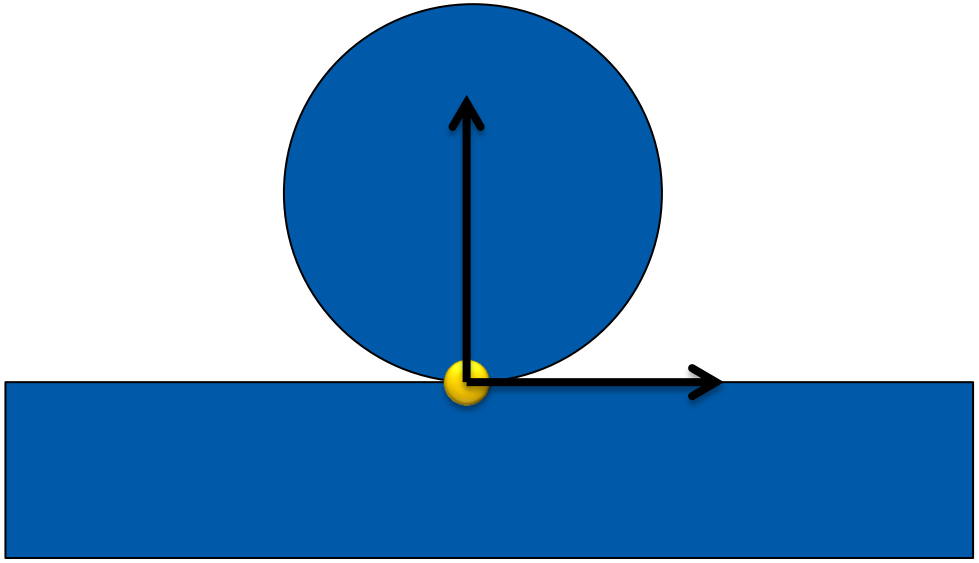
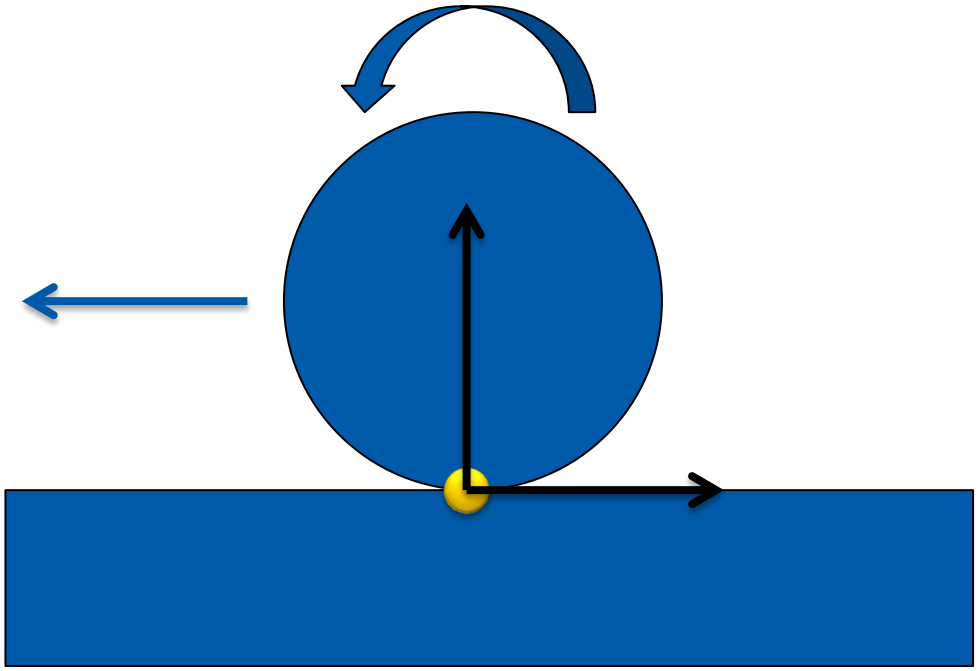
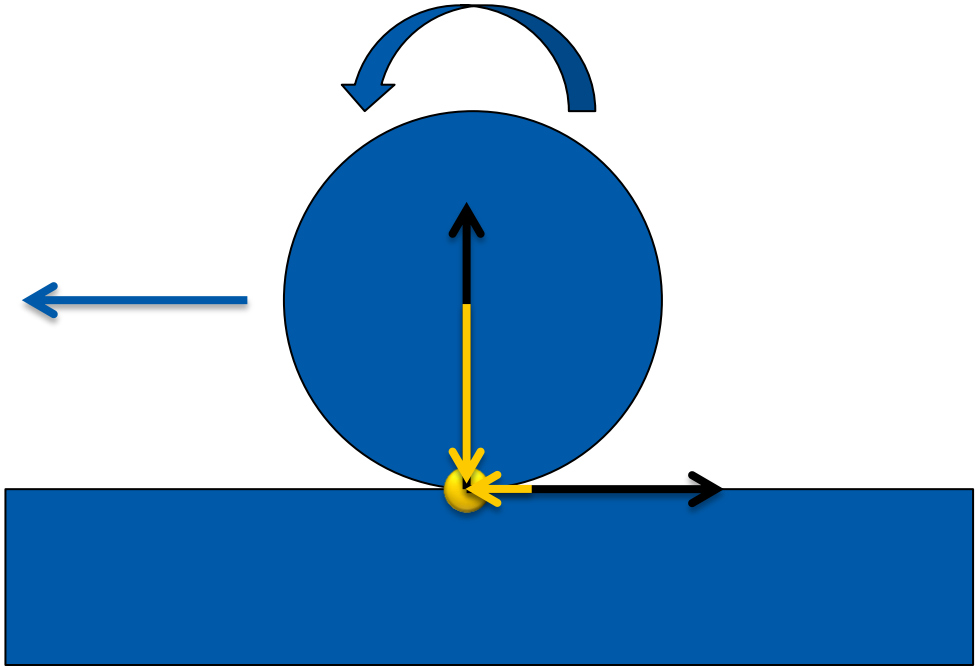
Find the collision basis



Identify the velocity of the collision point



Map velocity into the collision basis



X-Axis (= collision Normal)

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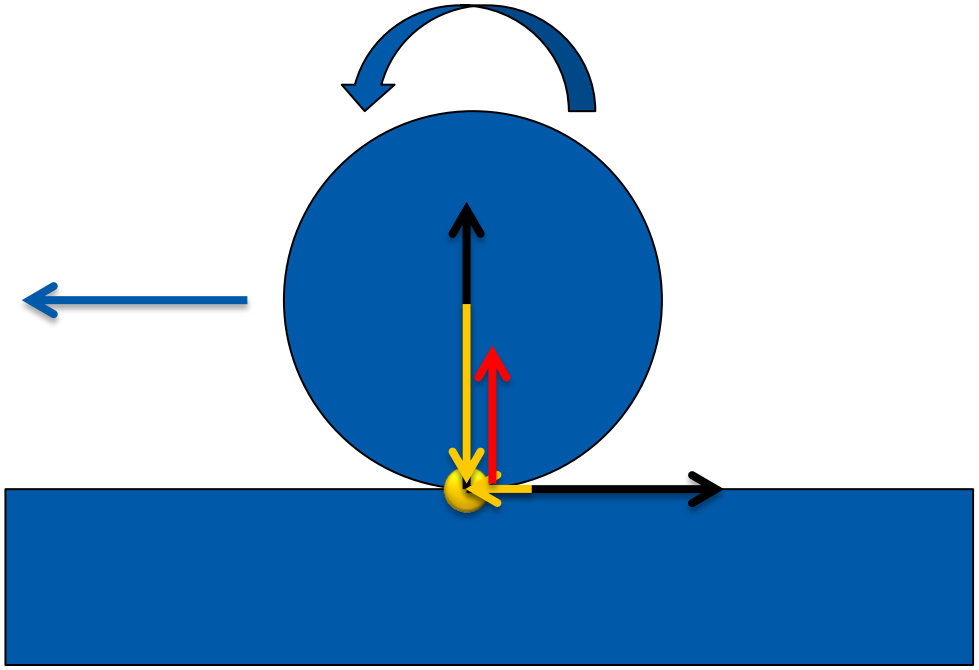
Separate the objects (what we did last lecture)



Y and Z-Axis

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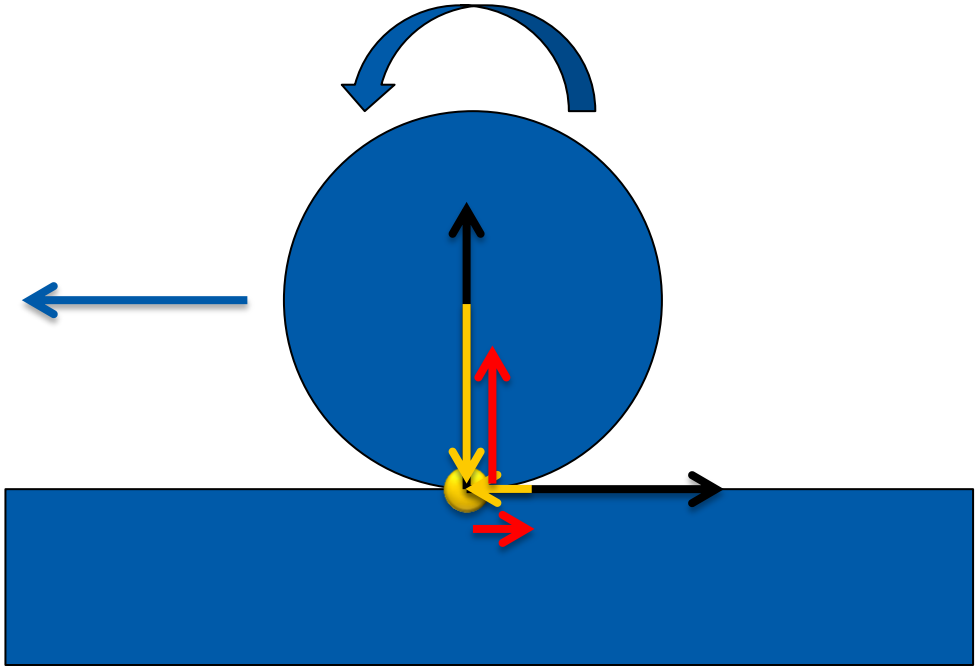
Handle Friction



Apply changes as impulses

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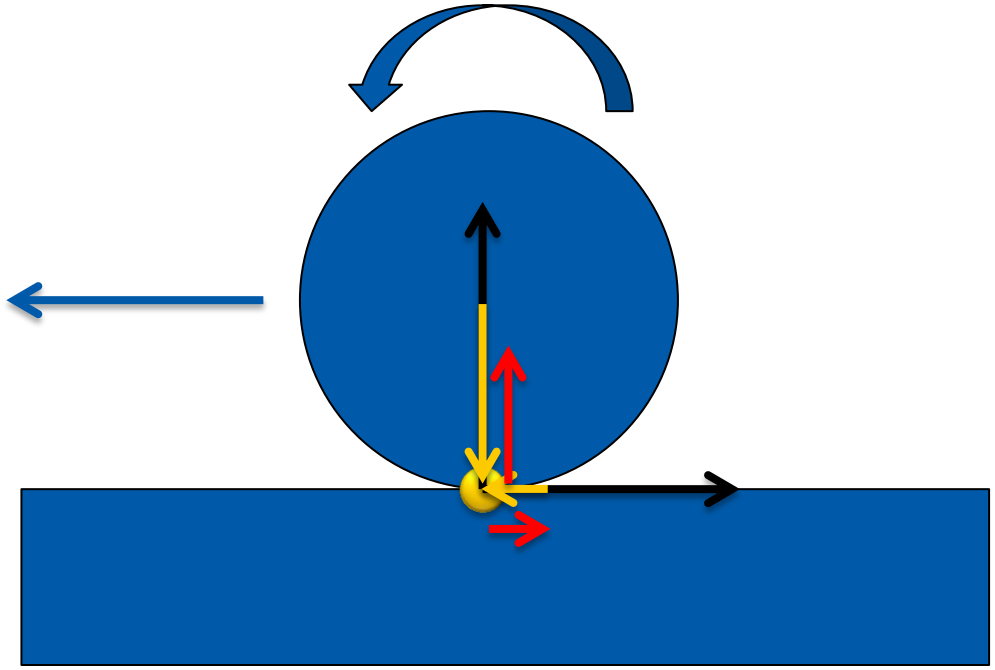
Changes to velocity and rotation



Exercise 8

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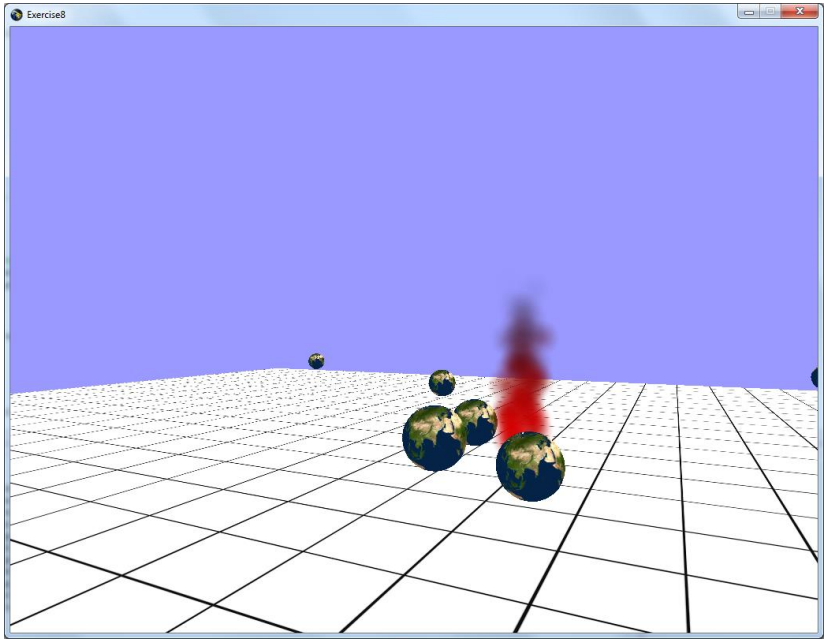
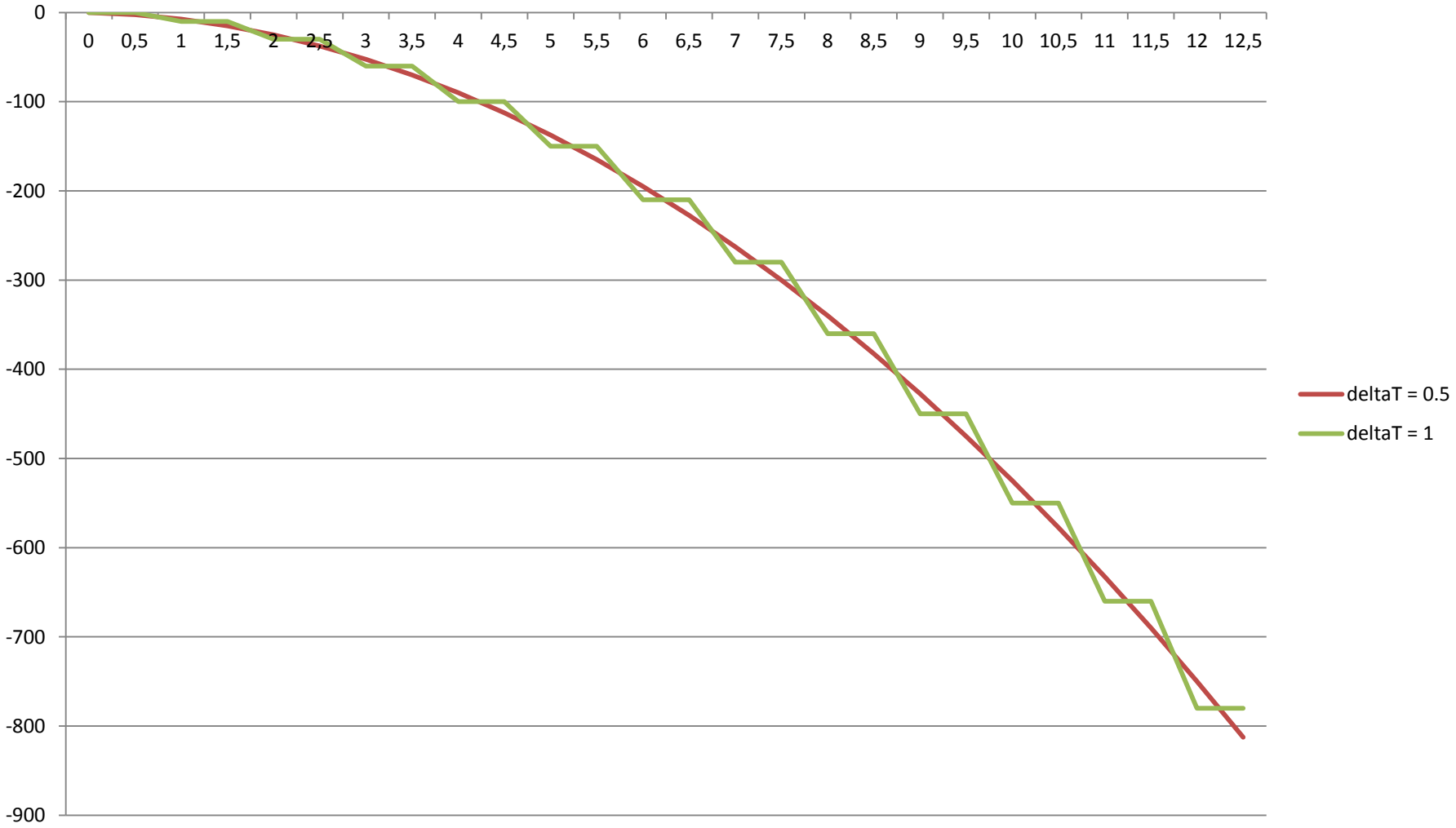
Practical Exercise

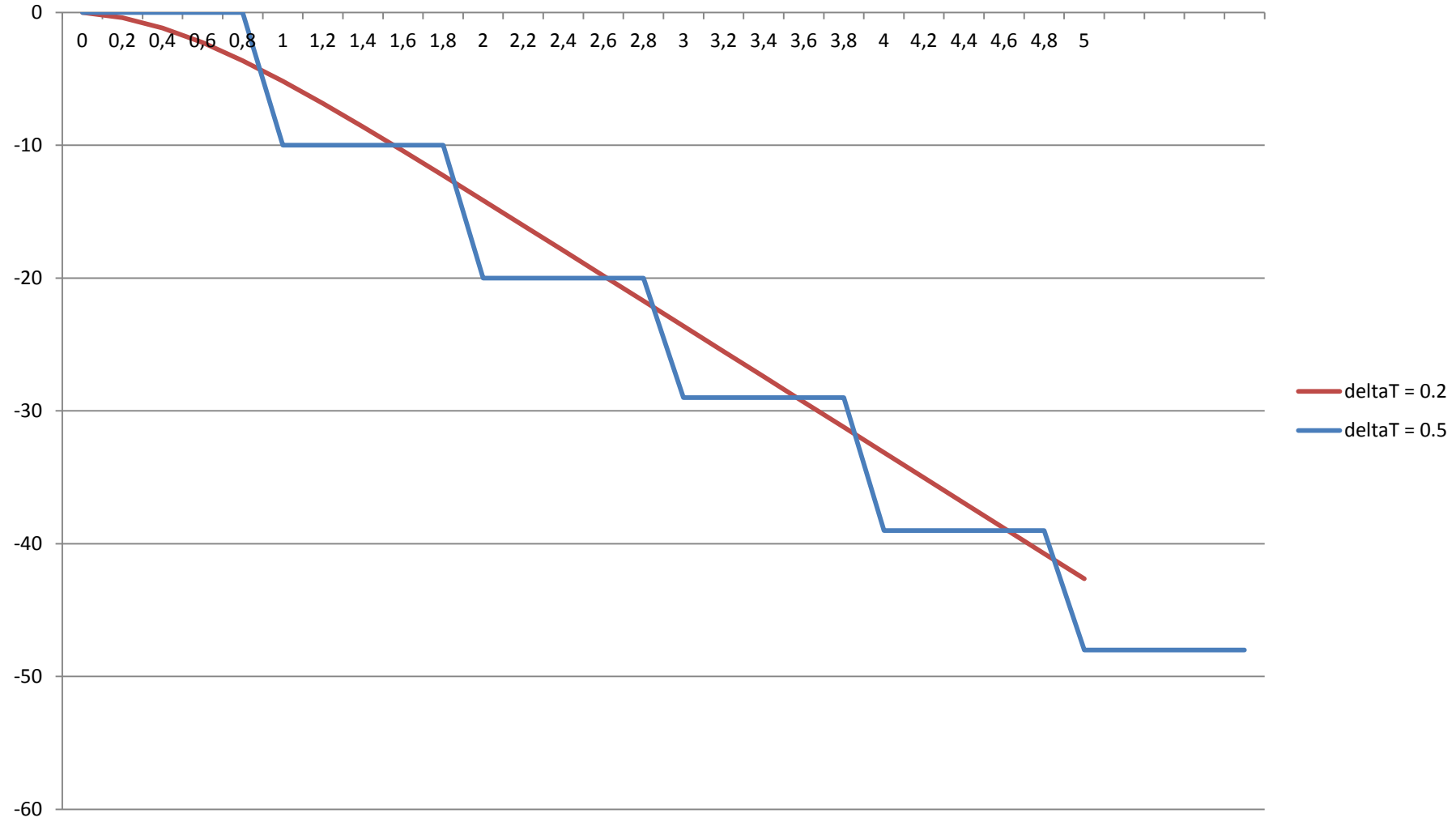
- Solution will be uploaded



Exercise 8 2.1



Exercise 8 2.2



Exercise 8 2.3

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Build a matrix for billboarding that keeps the y-axis in place

- Using only the view matrix is a large restriction
- Easier to construct with knowledge of the object's position

Structure of the view matrix's rotation part

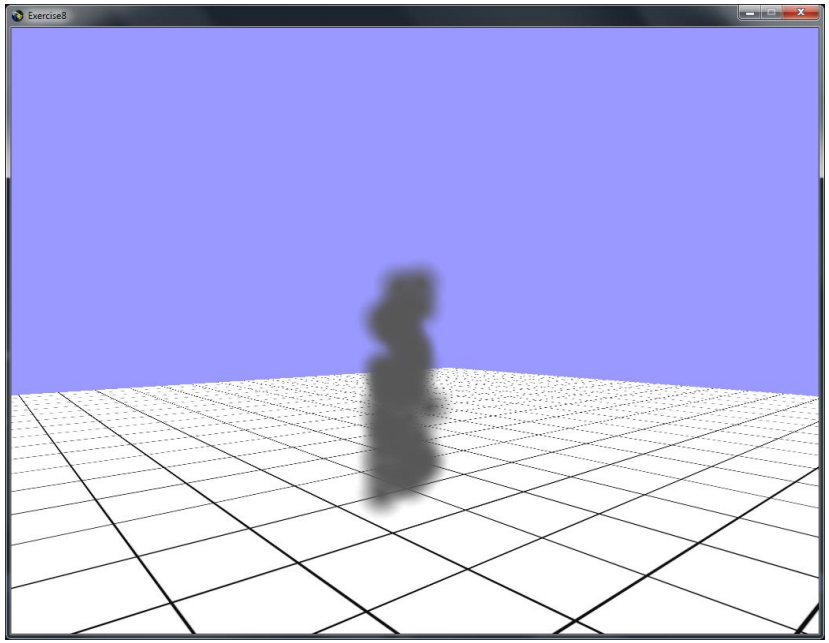
$$\begin{pmatrix} \boldsymbol{right} & \boldsymbol{up} & \boldsymbol{lookat} \\ \boldsymbol{right} & \boldsymbol{up} & \boldsymbol{lookat} \\ \boldsymbol{right} & \boldsymbol{up} & \boldsymbol{lookat} \end{pmatrix}$$

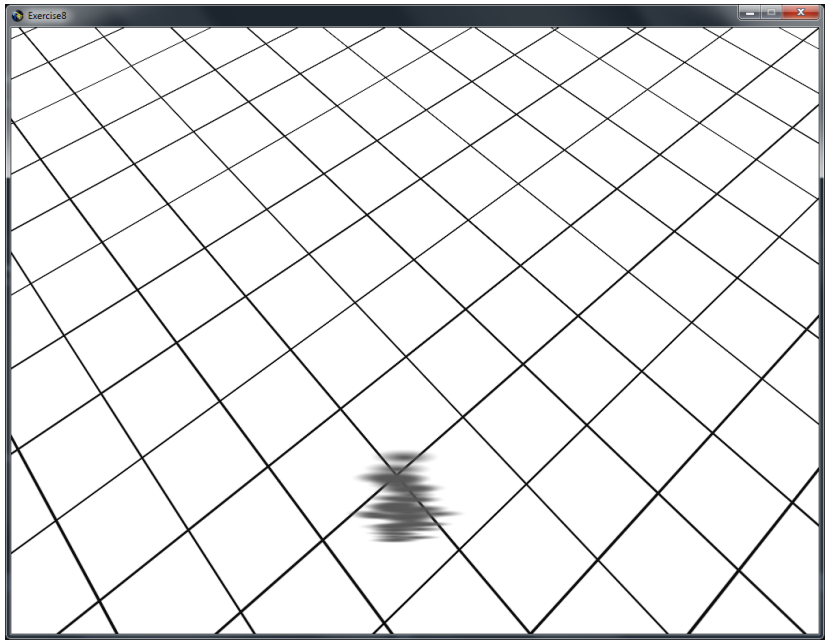
Change to

$$\begin{pmatrix} \mathbf{1} & \boldsymbol{up} & \mathbf{0} \\ \mathbf{0} & \boldsymbol{up} & \mathbf{0} \\ \mathbf{0} & \boldsymbol{up} & \mathbf{1} \end{pmatrix}$$

See also
http://www.lighthouse3d.com/opengl/billboarding/index.php3?billInt

Exercise 8 2.3





Exercise 9 – Practical Tasks

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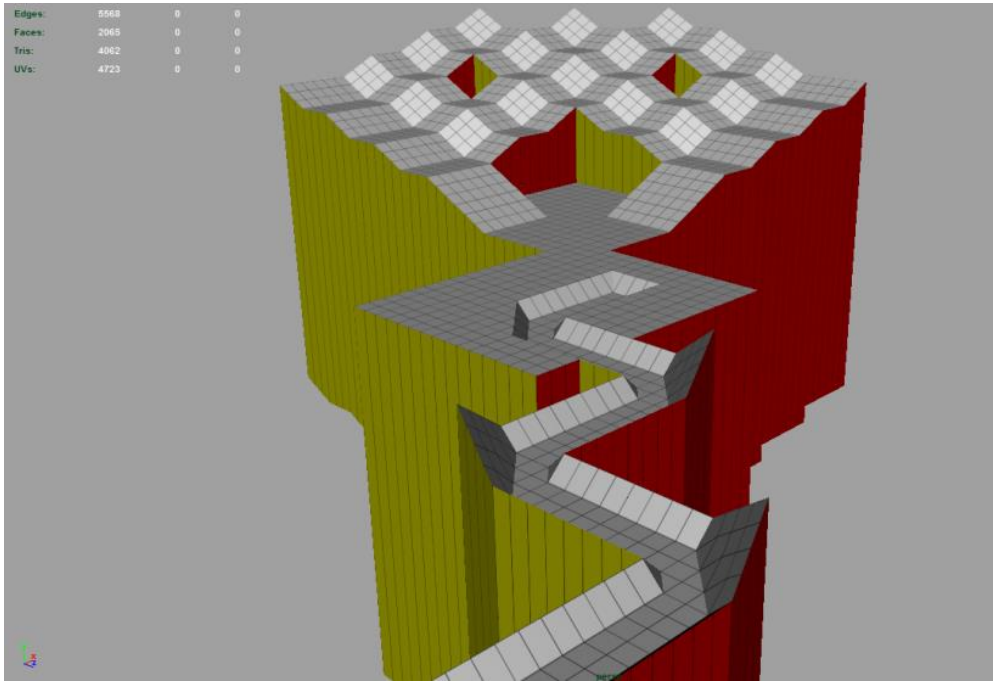
1.1 Triangle-Sphere-Intersection – Check one of the SAT axes

1.2 Construct the collision basis

1.3 Implement a goal area – See task 2.1



Exercise 9 – Theoretical Task

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Build the foundation for task 1.3

Describe a box-sphere intersection test

Either

- Derive your own and describe it (does not have to be optimized)
- Describe one from the literature (name your source)

Questions & Contact

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