Collision detection and handling

A major problem in many real-time animations.

Even modern high-budget games have problems!

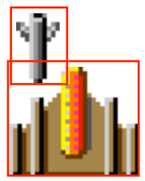
2D collision detection

Even in 2D, collisions is a non-trivial problem.

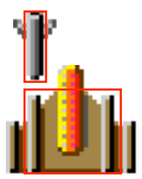
- Rectanges - easy
- Enclosing convex polygon(s)
- Pixel-level testing

2D collision detection with rectangles

Testing with the bounding box: often unsatisfactory. Too crude approximation!



Smaller rectangles make decent compromises.



Special cases

When using pseudo-3D, sprites in perspective, the shape outline is not usable.

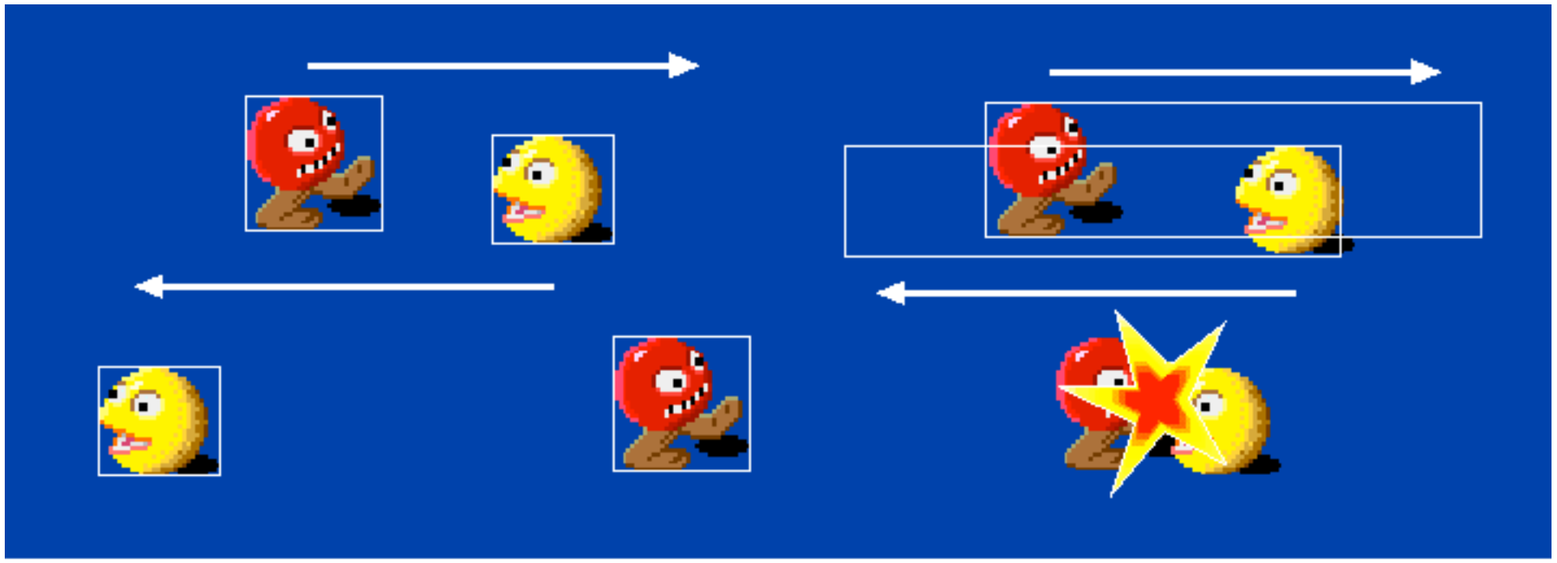
Simple approach: Modified box:

Wrong

Right

Moving objects

Fast moving objects may pass right through each other.



Wrong Right

An example of *temporal aliasing*

Fast-moving objects

- **Test with elongated shapes (sweeping)**
- **Test several times along the trajectory (multisampling)**

In 3D:

Polyhedra-polyhedra collisions

Naive method: Check all polygons in all objects against all polygons in all objects!

Polyhedra-polyhedra collisions

Practical methods:

1) Separate into broad phase and narrow phase

2) Simplified shape(s) matching a complex shape

Broad phase - narrow phase

Really three phases:

Global phase

Bounding shapes phase

Broad phase

Narrow phase

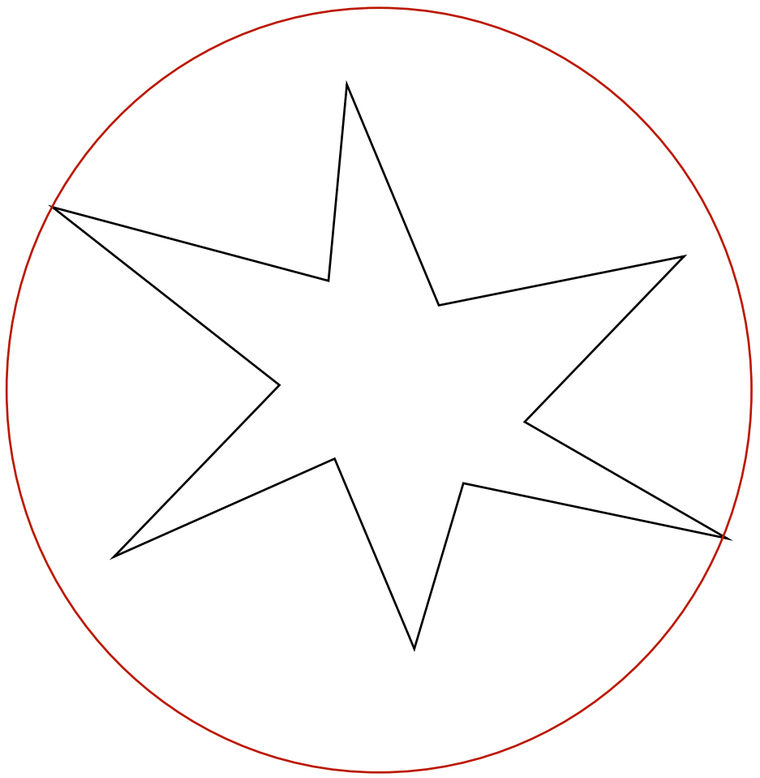
Bounding shapes phase

Make simple checks to see if objects are so close that we should test in detail!

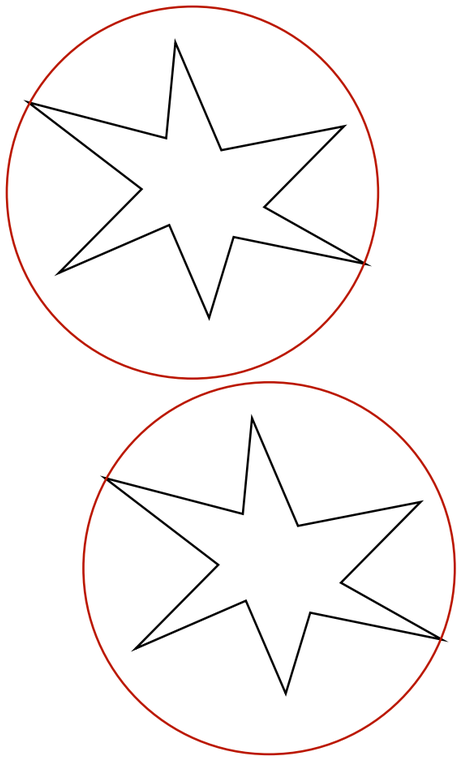
Use simple bounding shapes!

Typical shapes:
- **Sphere**
- **AABB (axis aligned bounding box)**
- **OBB (oriented bounding box)**

Sphere

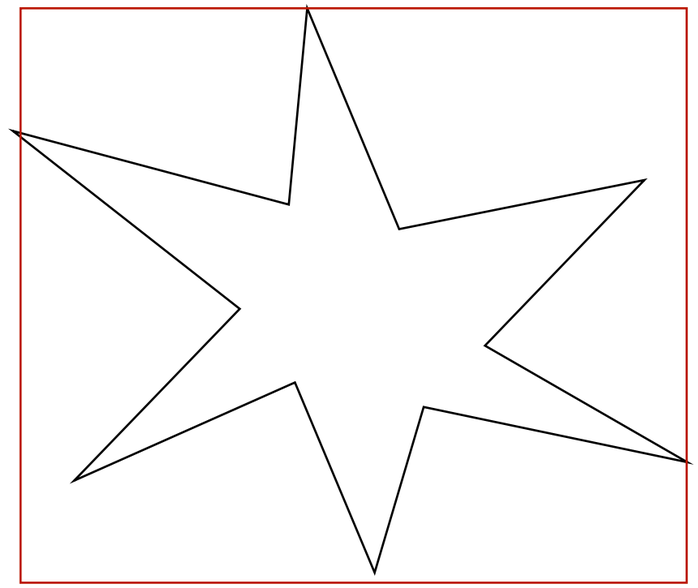


Sphere

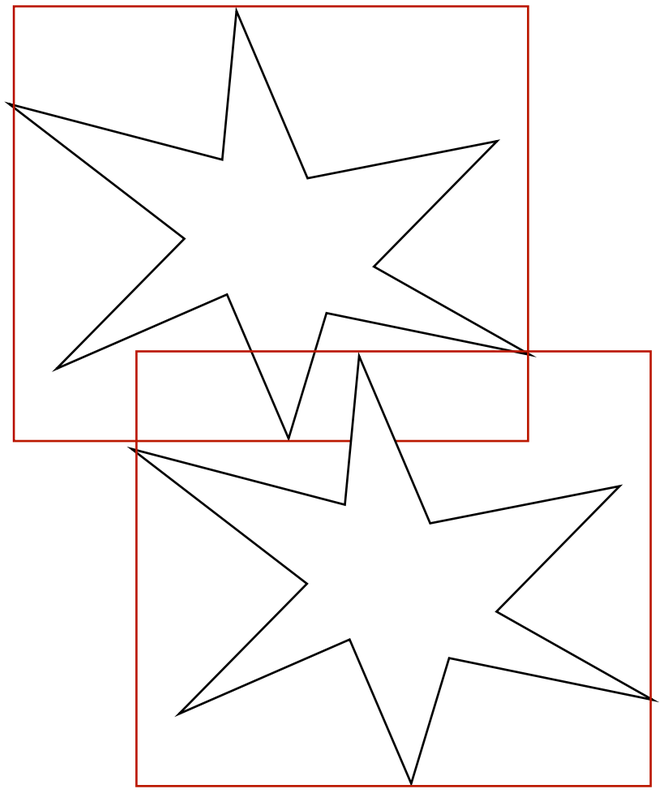


- **Very simple tests. $d^2 < (r_1 + r_2)^2$**
- **Calculate radius once and for all. Never changes for rigid objects. Loop through all vertices, pick biggest distance to center.**
- **Rotation allowed!**
- **Good fit for compact objects.**
- **No flat surfaces, object can not rest on each other.**

AABB



Axis aligned bounding box



AABB

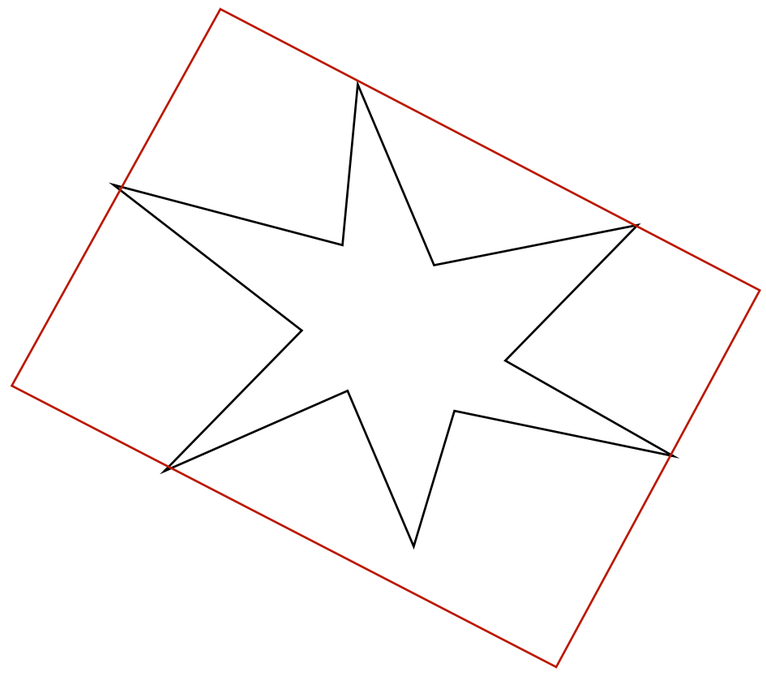
- **Very simple tests. 6 tests, like the 2D case.**

- **Calculate by finding max and min along each axis.**

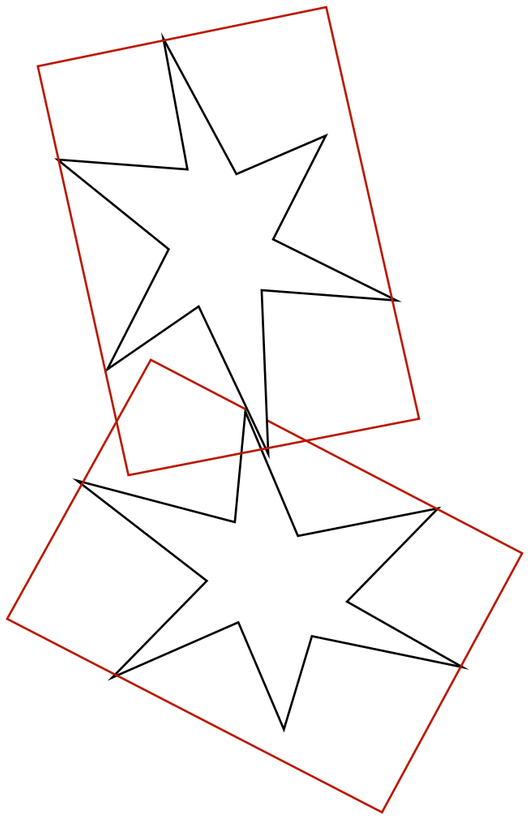
- **Can’t be rotated freely!**
1) Recalculate on rotation.
2) Make new AABB from rotated vertices of AABB.

- **Not very good fit on many objects.**

OBB
Oriented bounding box

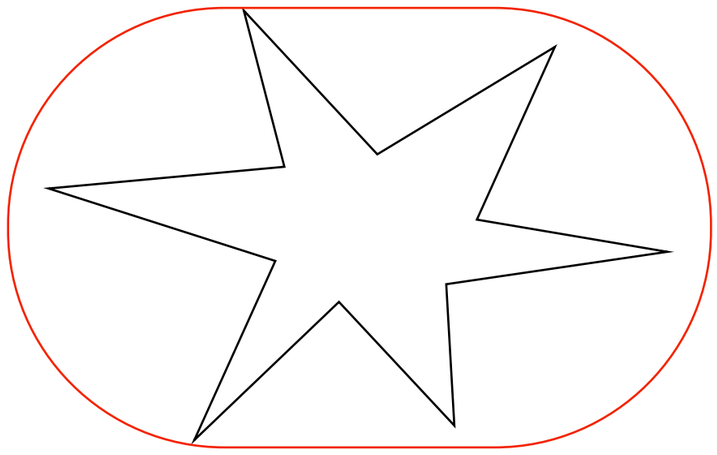


OBB
Oriented bounding box

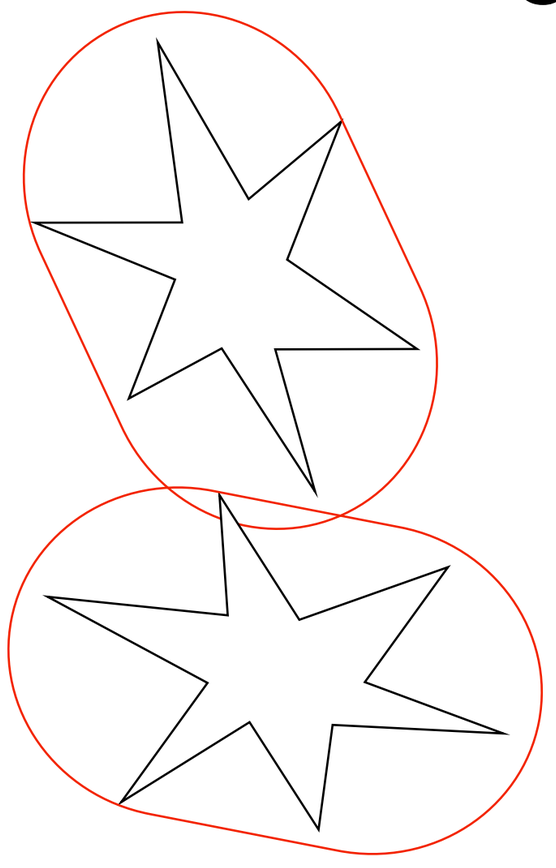


- **Good fit, you can find smallest possible box. Few false hits.**
- **Complicated tests.**
- **Rotation allowed.**

Capsule



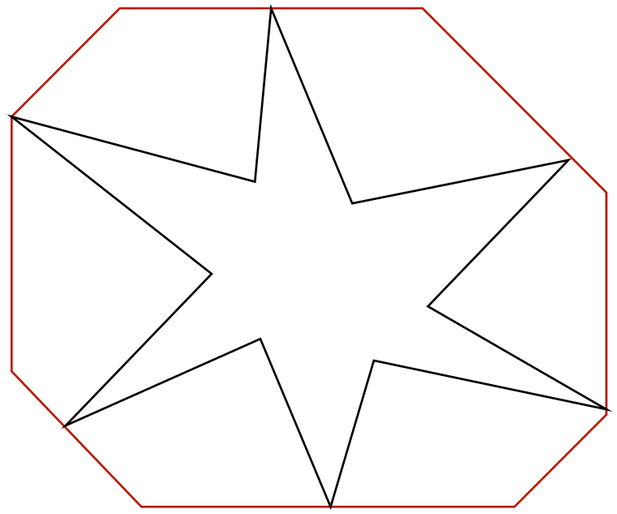
Capsule
Cylinder + 2 half spheres



- **Good fit, you can find smallest possible box. Few false hits.**
- **Fairly complicated tests - but easier than OBB.**
- **Rotation allowed.**

k-DOP

Discrete oriented polytope with k sides

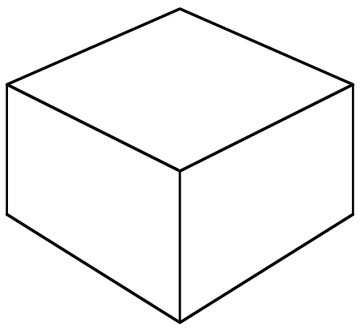


Like AABB but you can cut off corners and sides
Fairly simple tests
Fewer false hits

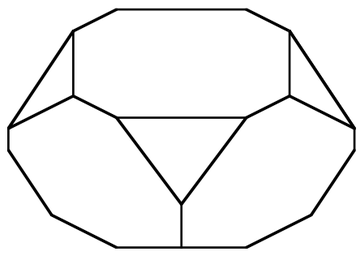
k-DOP
Discrete oriented polytope with k sides

Four kinds:

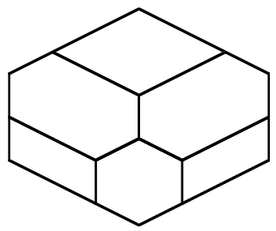
6-DOP (= AABB)
14-DOP (corners)
18-DOP (sides)
26-DOP (sides and corners)



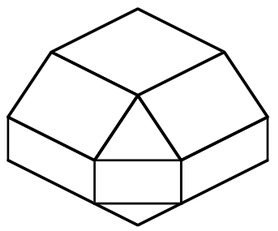
6-DOP



14-DOP



18-DOP



26-DOP

Balancing the broad and narrow phases

$$T = N_V C_V + N_p C_p$$

Simple broad phase - many false hits - high N_p.

Elaborate broad phase - few false hits - lower N_p but high C_V.

Narrow phase

Separating Axis Theorem (SAT)

Containment/intersection test

Volume intersection

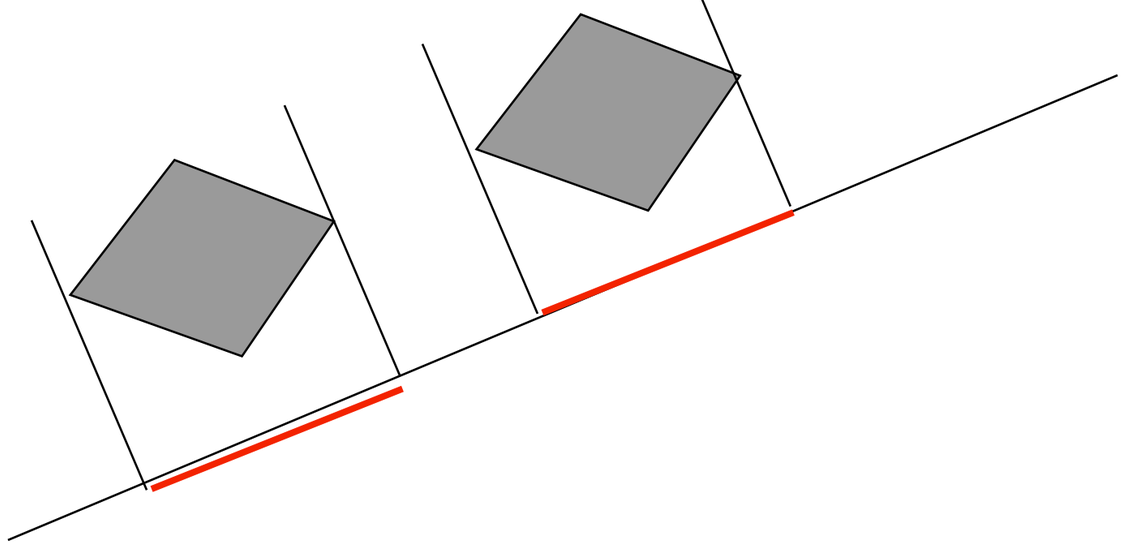
Advanced methods: GJK

Separating axis theorem (SAT)

and its application on collision detection

Separating axis theorem

Two convex objects do *not* overlap if there exists a line (axis) onto which the two object's projection do not overlap



Really ”Separating plane”

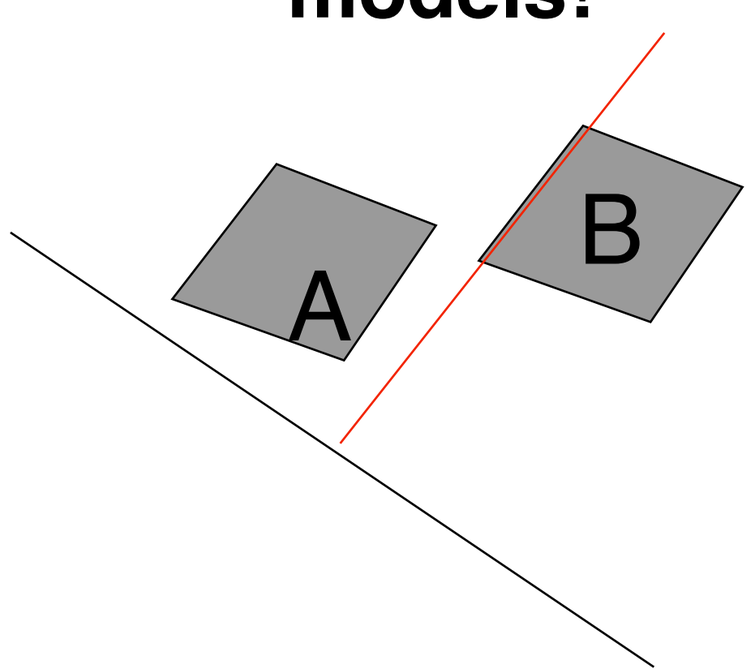
Axis = normal vector of separating plane

Can you find a plane between them?

Problem: The number of possible planes/ axes to test are *infinite*!

SAT in practice

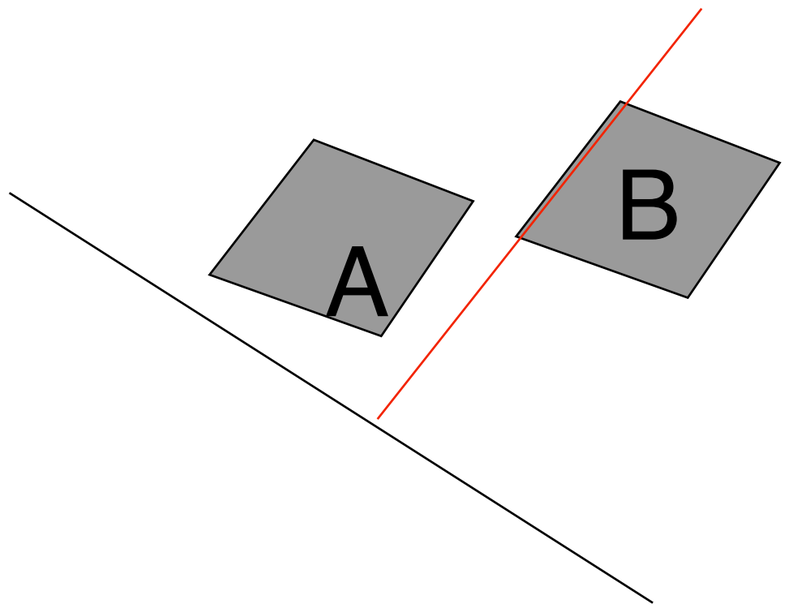
For polyhedra models, use the *faces* of the models!



Fairly simple in the 2D case

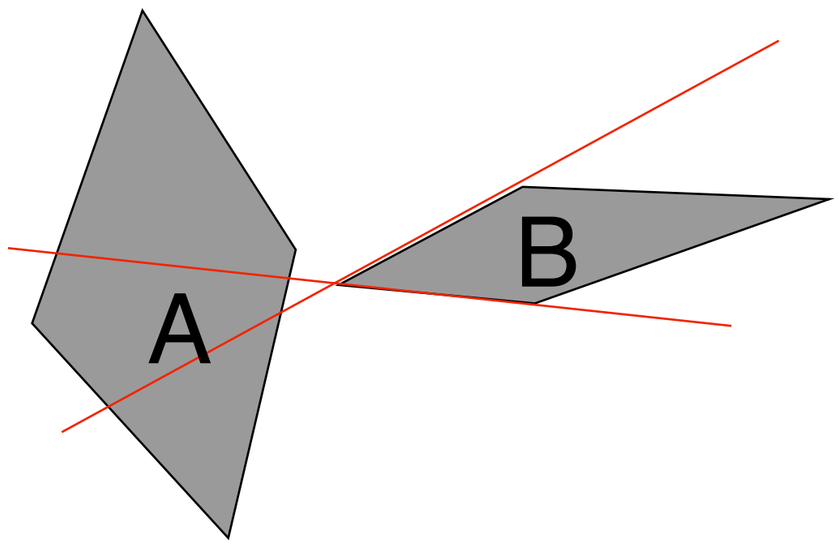
For every face in B, find plane equation

Test all vertices in A with dot product!



But you must go both ways!

There are configurations where one model has no single face that will exclude the other!



2D SAT algorithm

for all faces in A
let a be a vertex in A
hit = false
for all vertices b in B
diff = n • a - n • b
if diff > 0 then
hit = true
if not hit then
return false

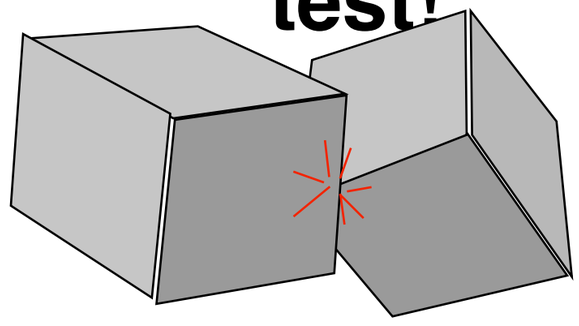
for all faces in B
(same algorithm with A and B reversed)

return true

SAT in 3D

Not as simple!

Two object meeting at an edge may fail the test!



We must add tests with more planes.

SAT in 3D

We must add tests with more planes. Which ones?

Cross product of an edge in a with an edge in b = additional potential separating plane

All edges in a * all edges in b!

=> Complete SAT on complex 3D objects is *expensive!*

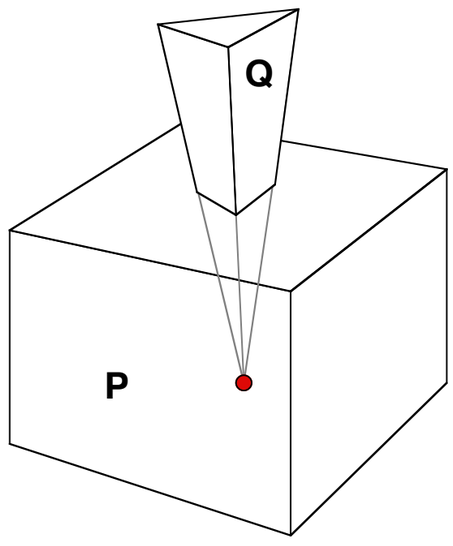
So how can SAT be useful?

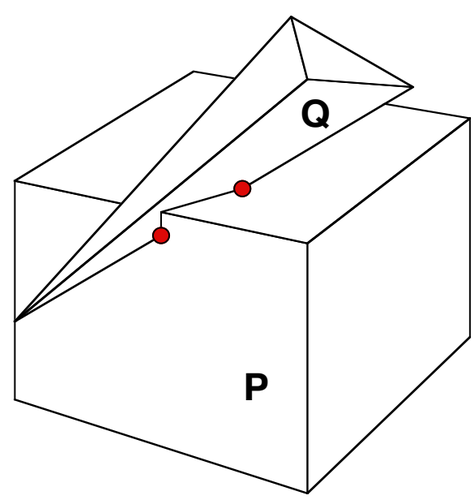
- **Simplify. Skip some tests, accept some false hits.**

- **Use SAT on simplified bounding shapes.**

- **Remember separating axis from previous test!**

Containment/intersection





Containment/Intersection

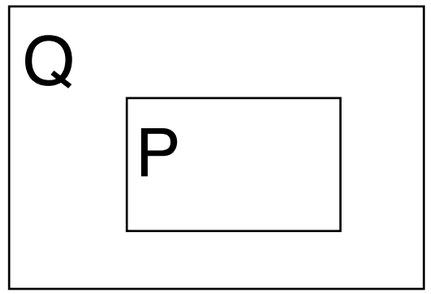
Exact test between two polyhedra, Q and P.

Two tests are needed:

1) Is any vertex in Q contained in P or vice versa?
2) Does any edge of Q penetrate a face of P?

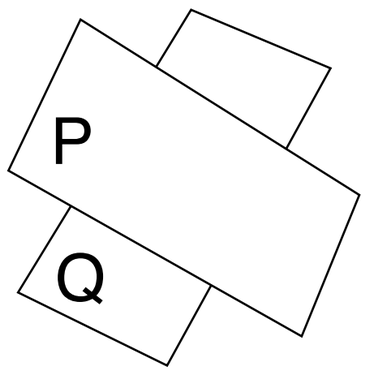
The need for all tests

1) in both directions:



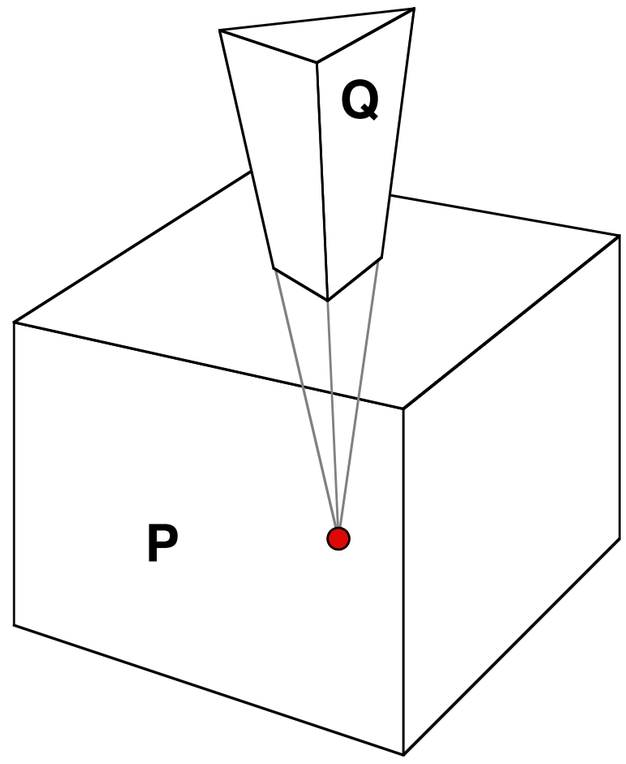
Q contains points in P, P contains no points in Q

2) when 1) fails:



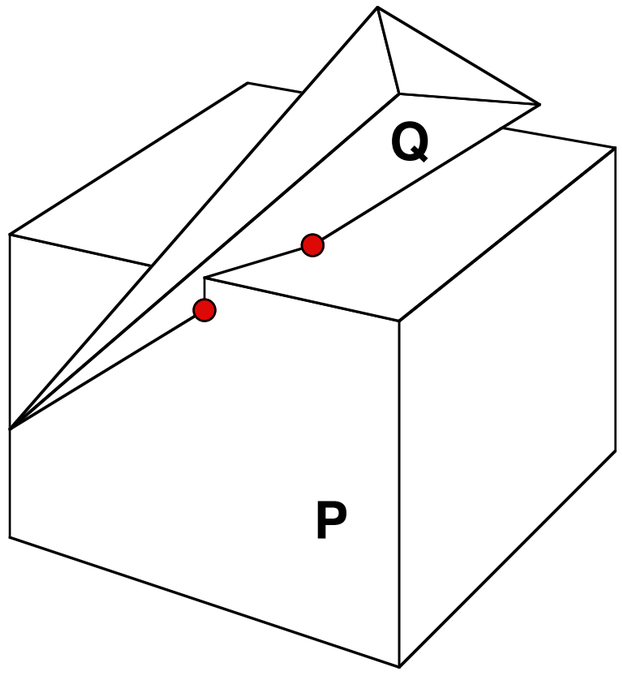
Neither P nor Q contain points of each other, but still overlap!

Test 1:



A point in Q is inside P

Test 2:

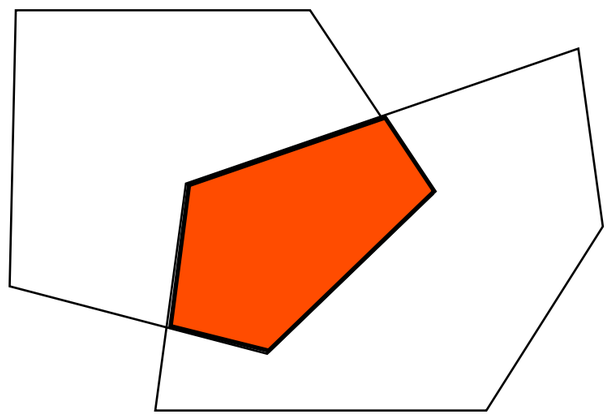


An edge of Q intersects sides of P

Volume intersection

Split P by any plane in Q, repeat. When all planes have been used, the intersection has been calculated.

Can be fairly fast if a good first plane is chosen.



Comparison

Full SAT

$$V_p*P_q+P_p*V_q + Ep*Eq*Vp + Ep*Eq*Vq$$ $O(N^3)$

Containment/intersection:

$$V_p*P_q+P_p*V_q + E_p*P_q+P_p*E_q$$ $O(N^2)$

Volume intersection:

$$\sum k^i P_q \approx P_q \log P_p$$ $O(N \log N)$

where i = 0 to P_p and k < 1.

Advanced methods

Volume intersection can sometimes simplify by starting ”right”.

Advanced methods take this even further. Remember last time, reduce test to very few. Just test the ”right test”.

Approximative methods
Collision shapes

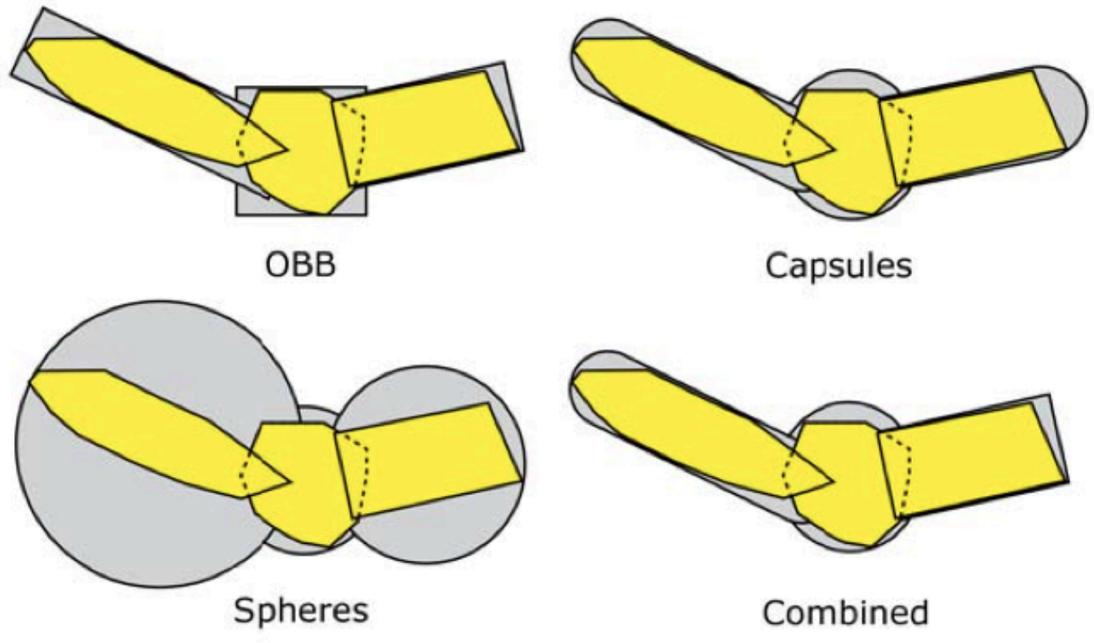
Simplify the narrow phase with simplified versions of the geometry

- Low-polygon version of a polyhedra
- A "standard" shape that follows the shape as closely as possible

The "narrow phase" more or less blends into the "broad phase"

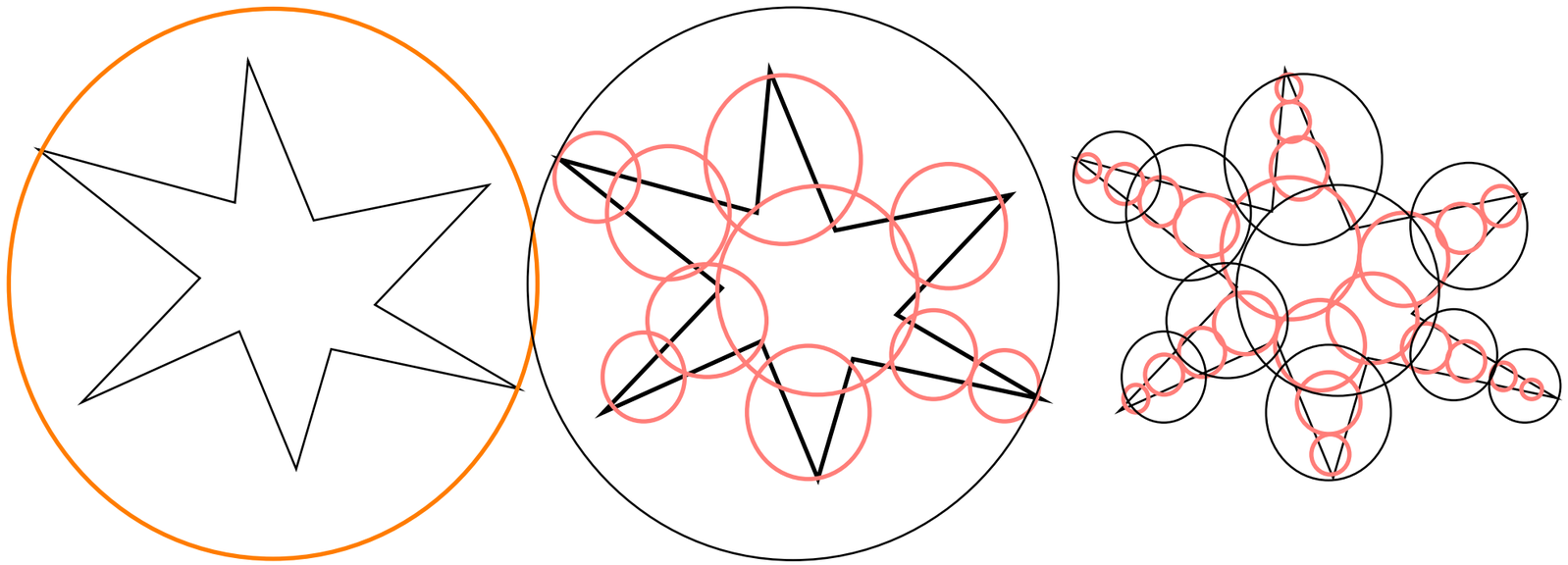
Multiple simple shapes

Use a number of very simple primitive shapes to approximate a complex shape



From:
Henrik Bäcklund,
Niklas Neijman,
"AUTOMATIC MESH DECOMPOSITION FOR REAL-TIME COLLISION DETECTION",
2013

Object hierarchies



Collision detection is done to the level that available time permits