Contact Manifolds

Erin Catto
Blizzard Entertainment

Executive Summary

- Constraint solvers need contact points to prevent penetration.
- We can use SAT to compute a contact manifold in one shot.
- We can use GJK to build up a contact manifold point-by-point.

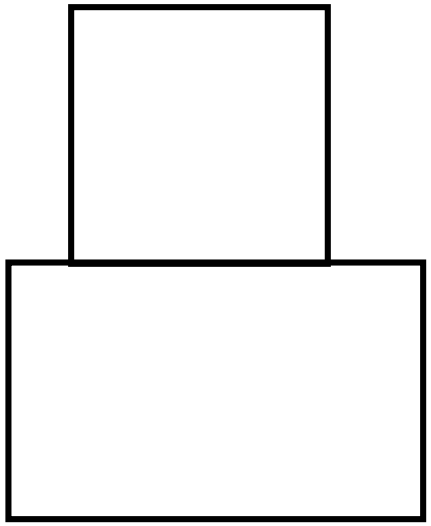
Contact

- Contact occurs when two shapes touch.
- We model contact to prevent penetration and to simulate friction.
- Modeling contact requires some geometry and a lot of *finesse*.

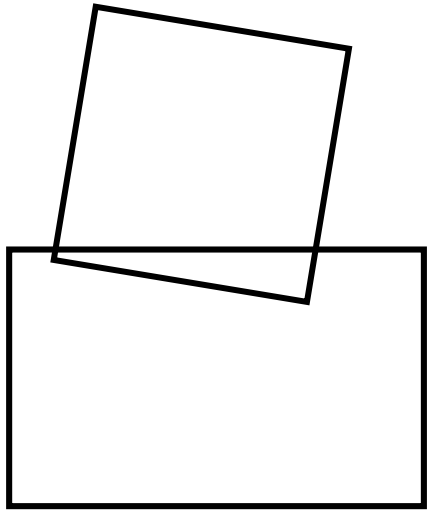
Contact Manifolds

- For convex polyhedra, a contact manifold is ideally a single point, a line segment, or a convex polygon.
- For general convex 3D shapes, the contact manifold is a convex 2D shape.
- Did I mention overlap?

Overlap Happens



What we want.



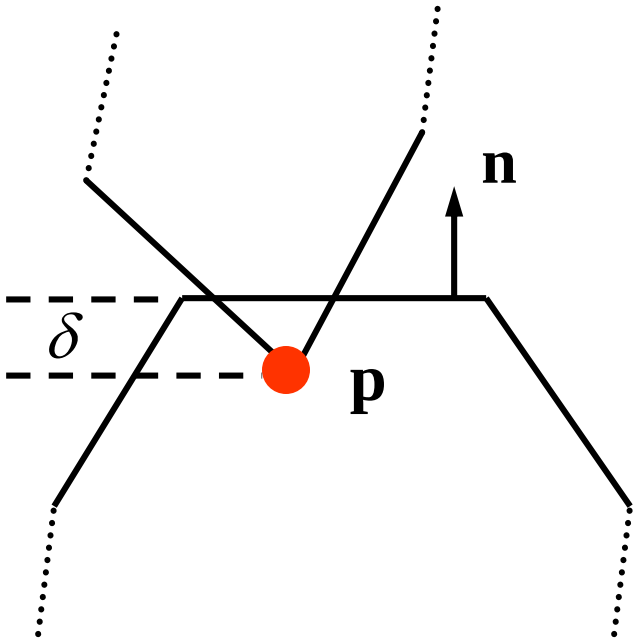
What we get.

Approximate Manifolds

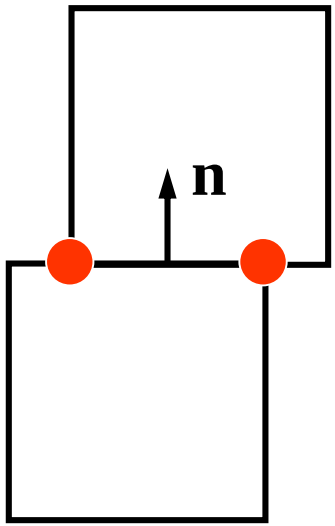
- We use a collection of *contact points* to approximate the contact manifold.
- Our goal is fast, stable, and plausible simulation.
- In this sense, computing good manifolds is an art.

Contact Points

- Position
- Normal
- Penetration
- Contact ID



Example Manifold

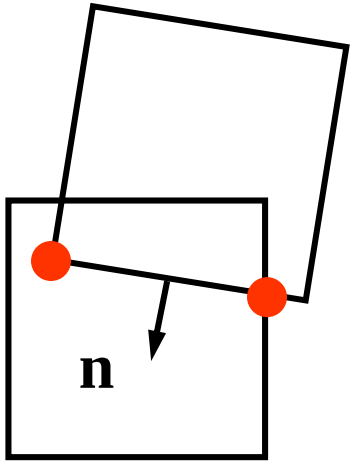


Two points and a common normal

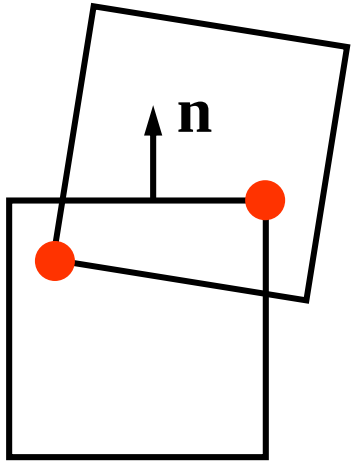
Contact Manifold Quality

- When objects penetrate significantly the contact manifold is fuzzy.
- Contact solvers like coherence.
- Be consistent from step-to-step.

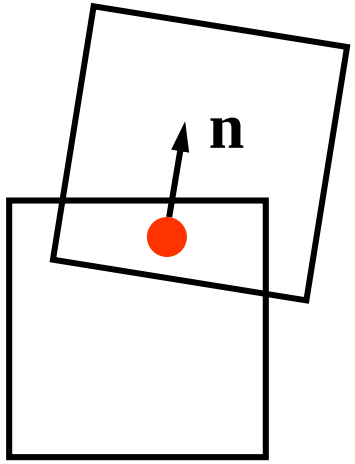
Fuzziness



manifold 1

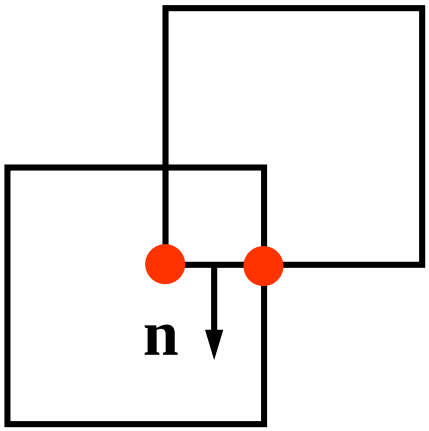


manifold 2

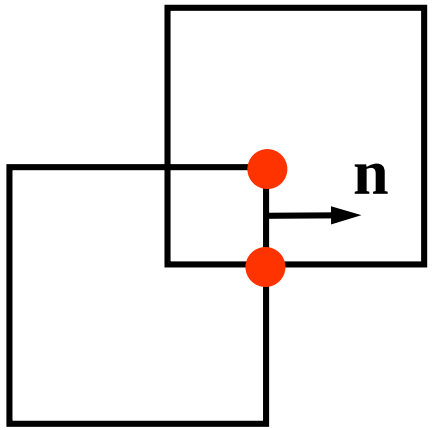


manifold 3

Extreme Fuzziness



manifold 1



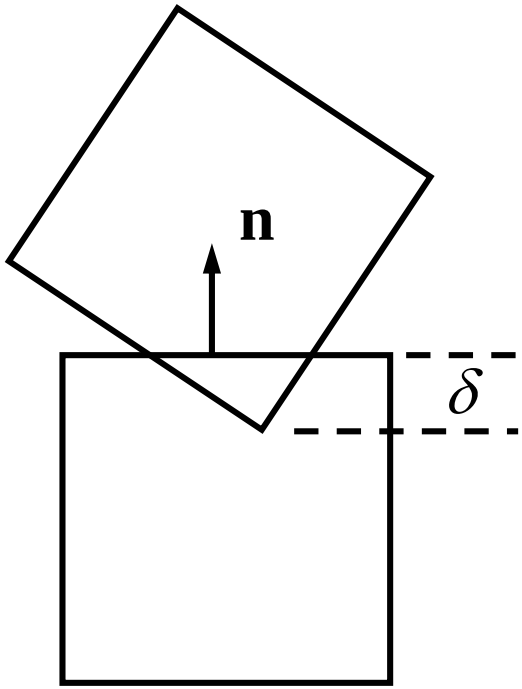
manifold 2

Using the SAT

- Mainly useful for convex polyhedra (boxes, triangles, etc).
- Find the axis of minimum penetration.
- For edge-edge contact, find the midpoint.
- For face contact, use Sutherland-Hodgeman clipping.

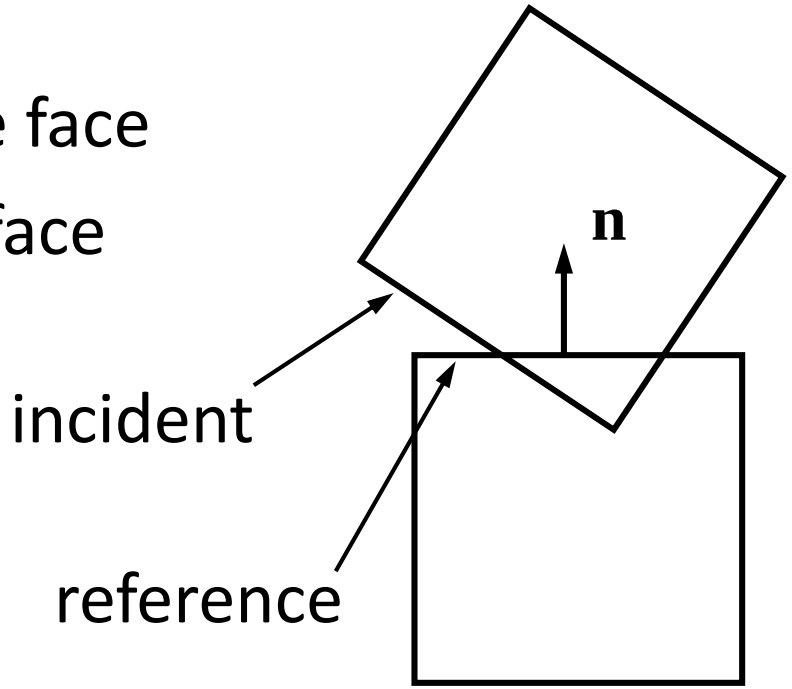
Example: 2D Box-Box SAT

- First find the separating axis with the minimum penetration.
- In 2D the separating axis is a face normal.



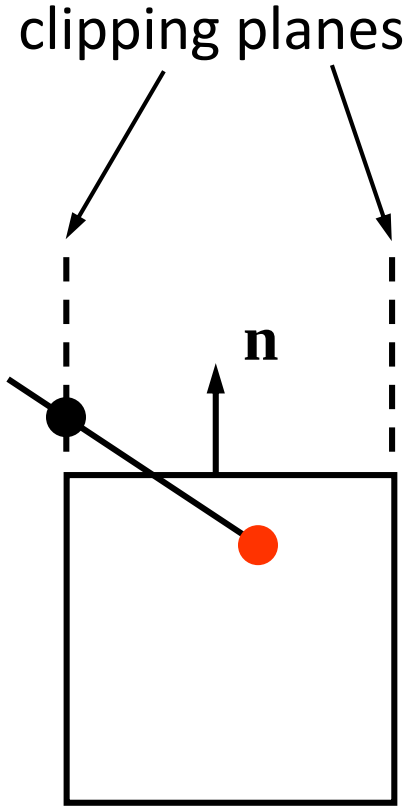
Box-Box Clipping Setup

- Identify reference face
- Identify incident face



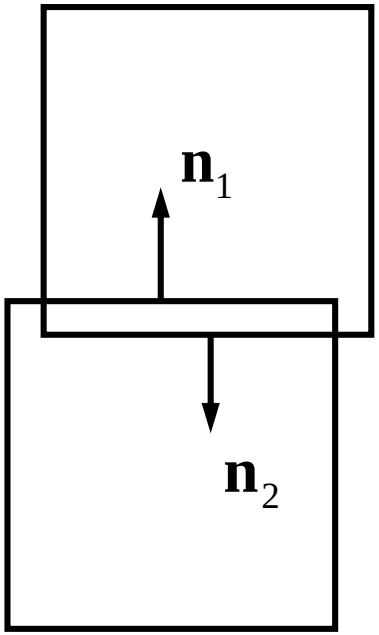
Box-Box Clipping

- Clip incident face against reference face side planes (but not the reference face).
- Consider clip points with positive penetration.



Feature Flip-Flop

- Which normal is the min separating axis?
- Apply weightings to prefer one axis over another.
- Improved coherence.



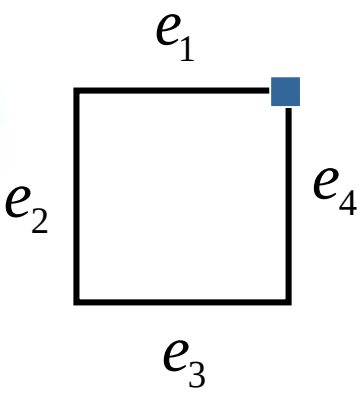
Coherence

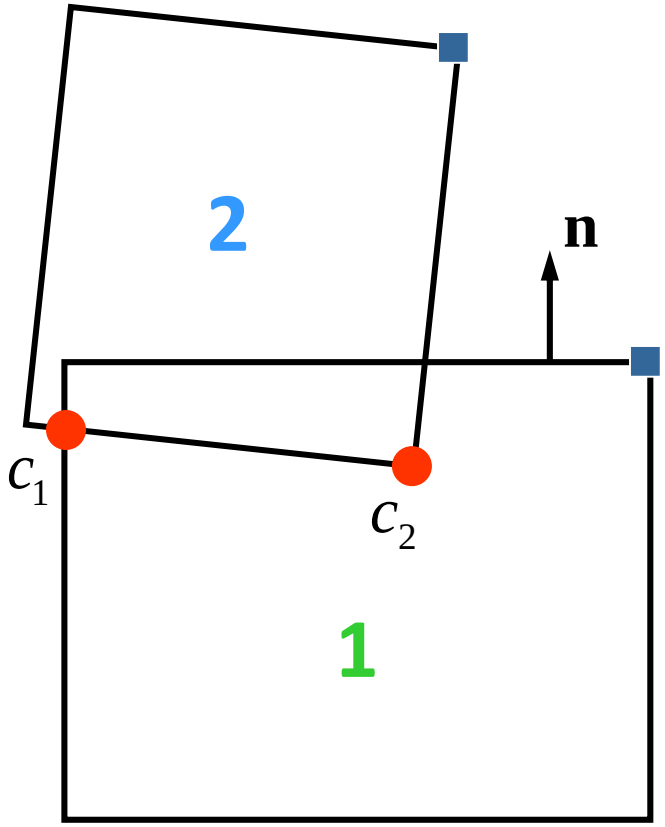
- Apply old force/impulse solution at the beginning of the step.
- Fewer iterations and greater stability.
- We need a way to match old and new contacts.

Feature-Based Contact Points

- Each contact point is the result of clipping.
- It is the junction of two different edges.
- An edge may come from either box.
- Store the two edge numbers with each contact point – this is the Contact ID.

Contact Point IDs





c_1

box 1 edge 2

box 2 edge 3

c_2

box 2 edge 3

box 2 edge 4

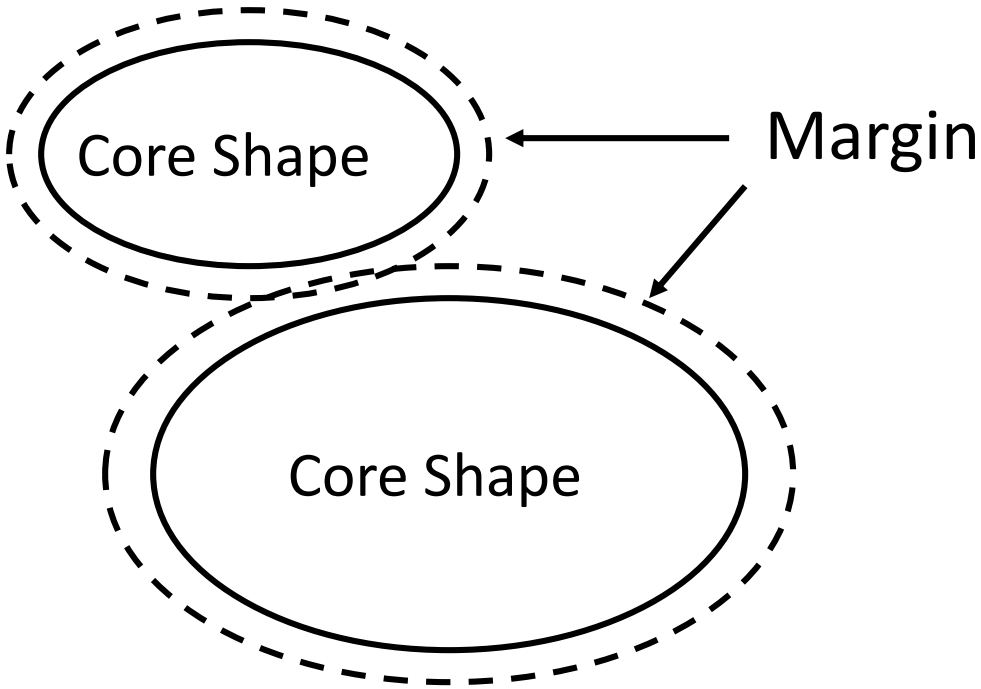
GJK Contact Points

- Three cases:
  - No contact
  - Shallow contact
  - Deep contact

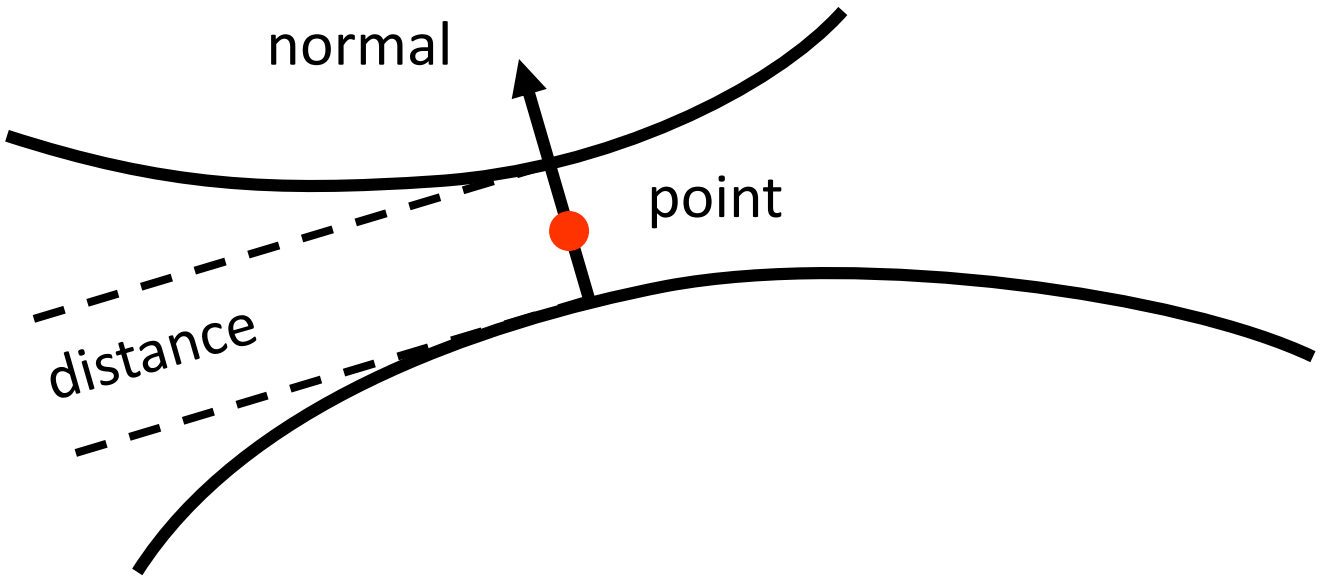
GJK Shallow Contact

- The support points are scaled up by a small margin to detect contact.
- Compute the closest points (no margin).
- This gives the position and normal.
- The penetration is the margin minus the true distance.

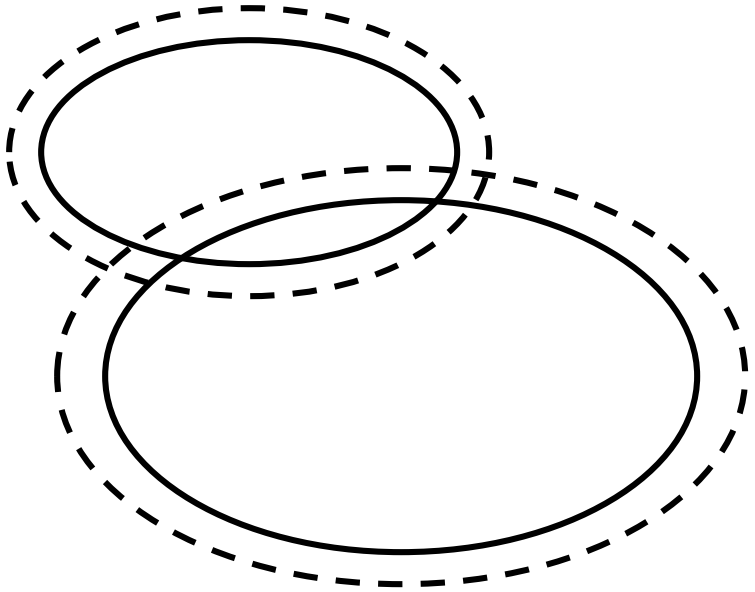
GJK Contact Margins



GJK Contact Point



GJK Deep Contact



An awkward encounter …

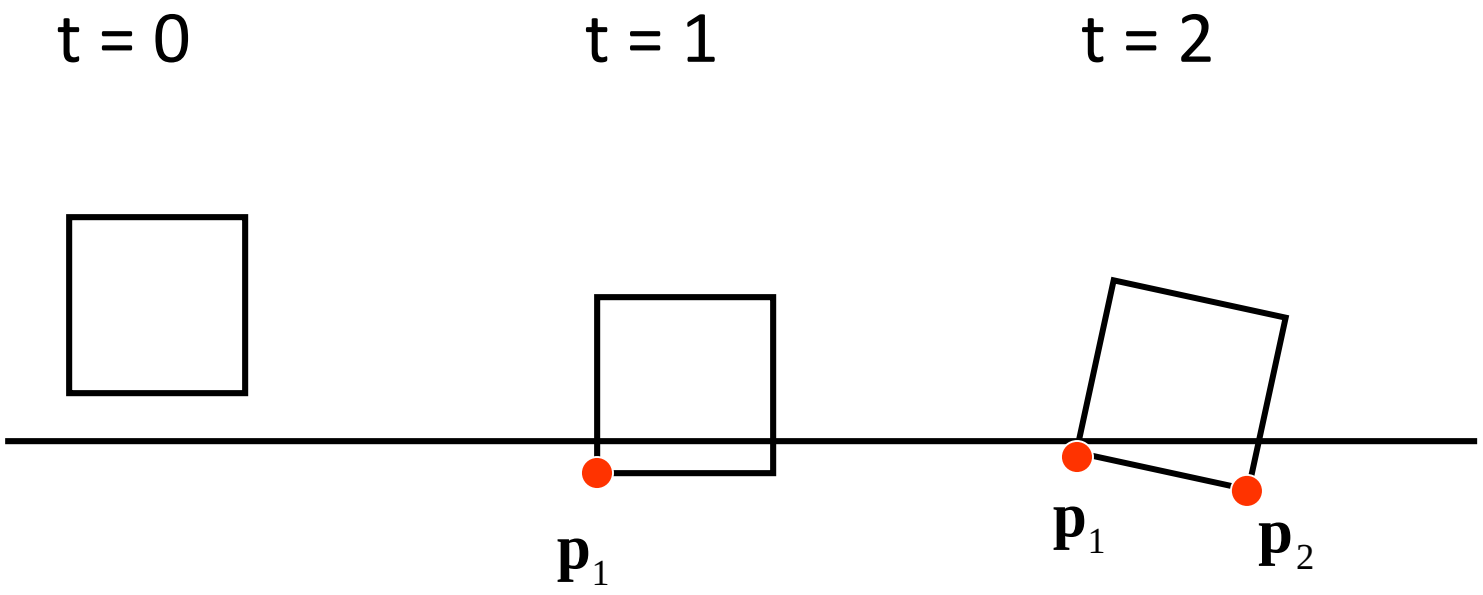
Deep Contact

- Use some *other* algorithm.
- It will be slower than GJK, but it won't last long.
- SAT, EPA, brute force.
- Read Gino's book to learn EPA.

GJK Manifolds

- GJK only gives one contact point at a time.
- We hold on to and *treasure* each contact point.
- Build a manifold over several time steps.
- This automatically provides coherence.

Building the Manifold



Manifold Persistence

- Track the points in each body.
- If the points move too far apart, dismiss them.
- This is bad for sliding.
- Use Contact IDs?

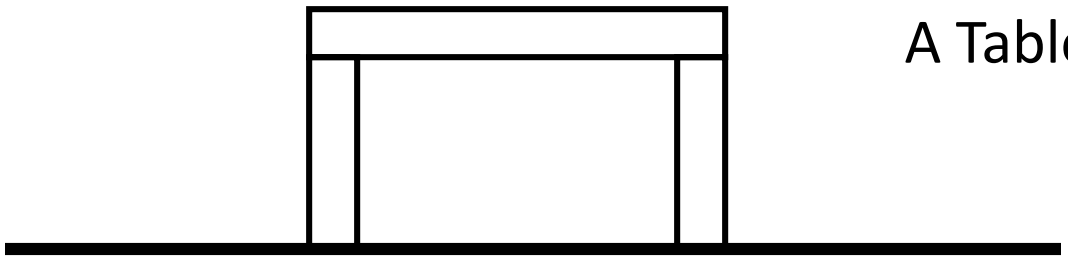
Adding New Points

- Keep a minimal set of points per manifold (e.g. 4 points).
- Reject new points that are too *close* to old points.

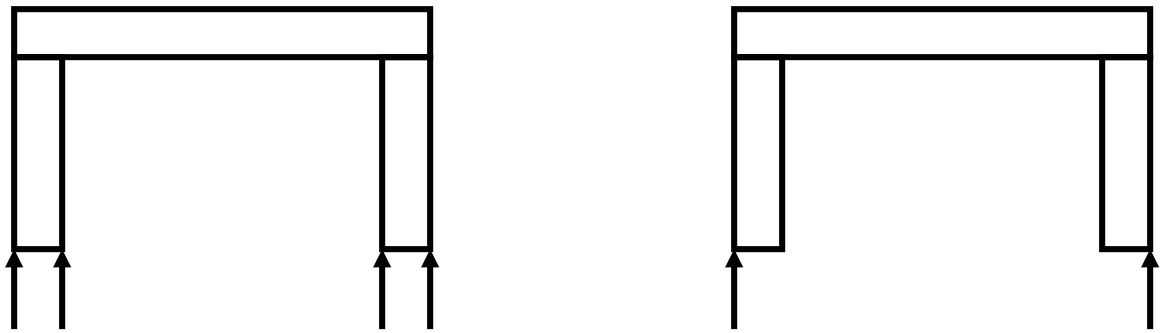
Manifold Reduction

- This applies to one-shot and incremental manifolds.
- We want to keep the minimum number of contact points for a stable simulation.
- This improves performance drastically.

Example Reduction



A Table



Before

After

Further Reading

- http://www.gphysics.com/downloads/
- http://www.continuousphysics.com
- Collision Detection in Interactive 3D Environments by Gino van den Bergen
- Fast Contact Reduction for Dynamics Simulation by Adam Moravanszky and Pierre Terdiman in Game Programming Gems 4.