Fire Simulation

Jared Heinly

Definition

"Fire is the rapid oxidation of a material in the chemical process of combustion, releasing heat, light, and various reaction products." – Wikipedia

Motivation

- Video Games
- Movies
- Fire Prevention

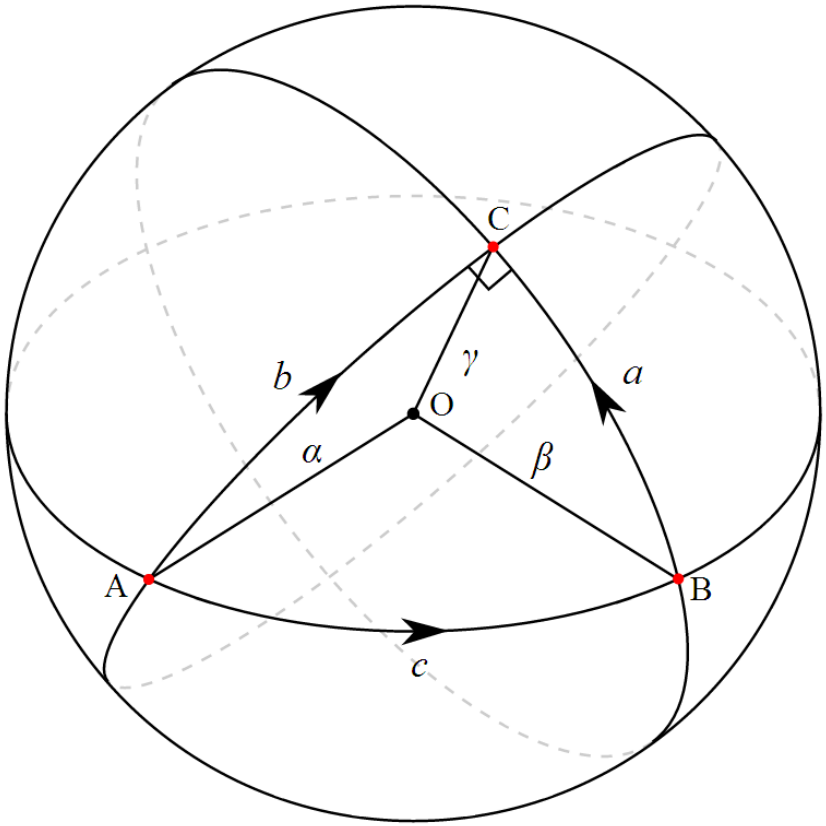
Far Cry 2 (Ubisoft)

Overview

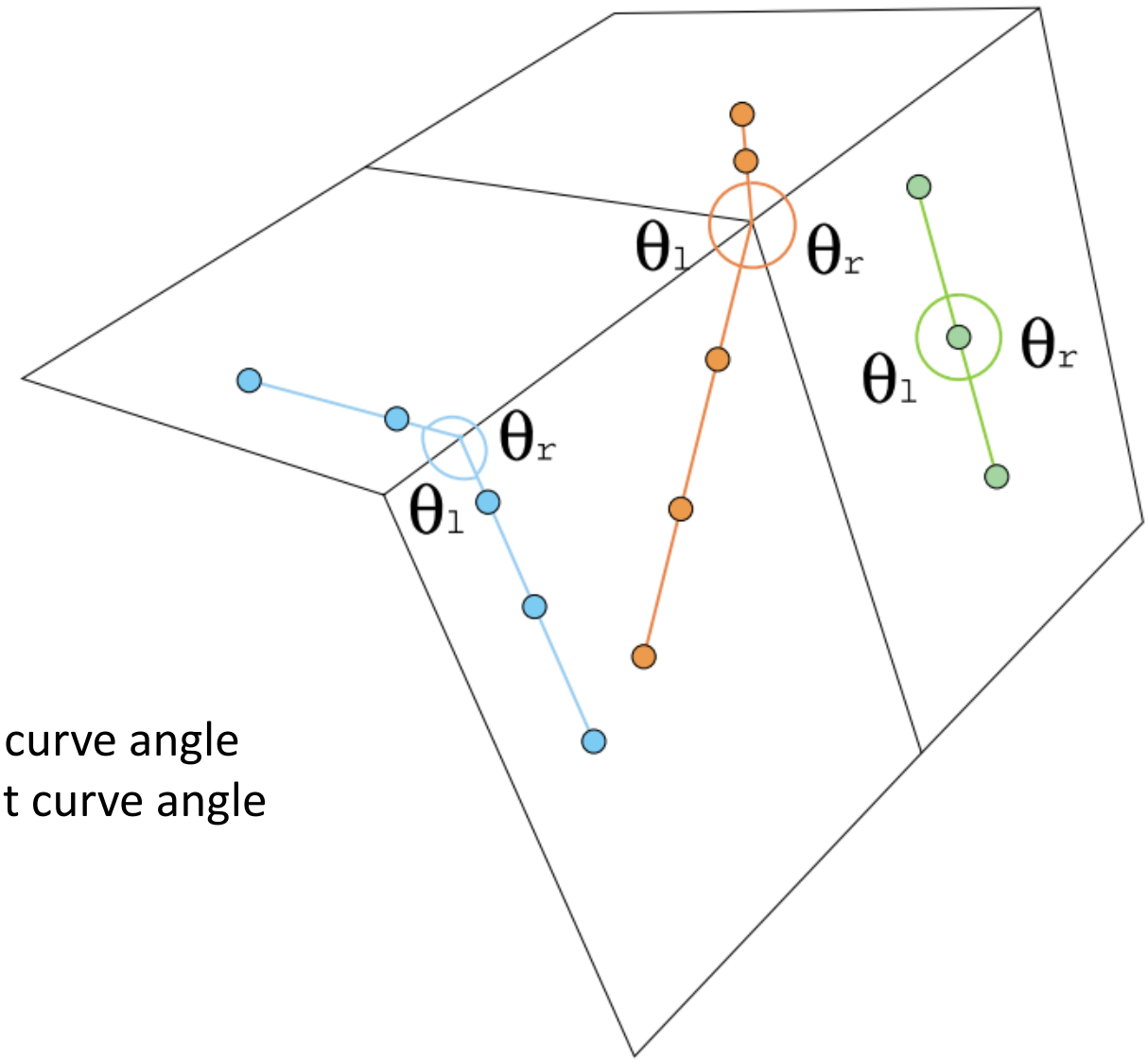
- Fire Propagation
  - Geodesics
  - Front Expansion
  - Front Merging
- Flame Simulation
  - Fire Particles
  - Wind Fields
  - Flame Skeletons
- Results

Geodesics

- Extension of Euclidean straight lines to a curved surface



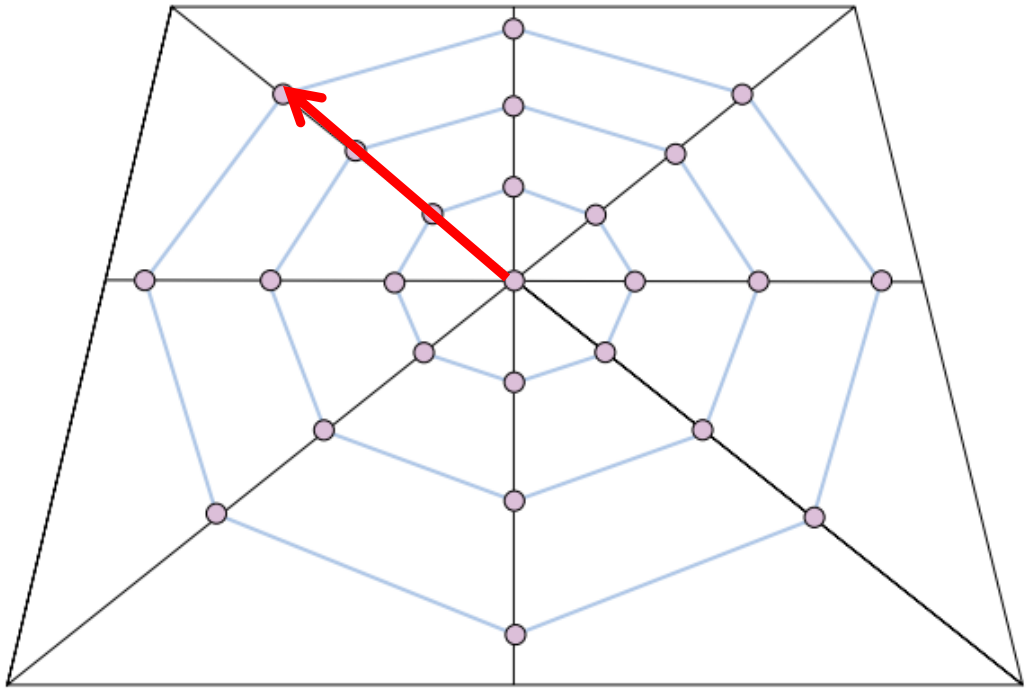
Geodesics

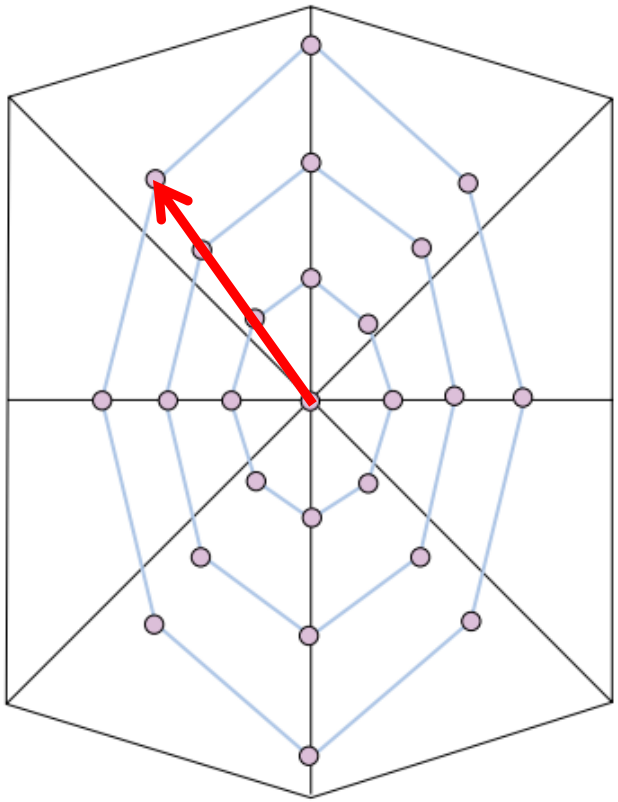


θ_l – left curve angle
θ_r – right curve angle

Why Geodesics?

- Model Fire Propagation

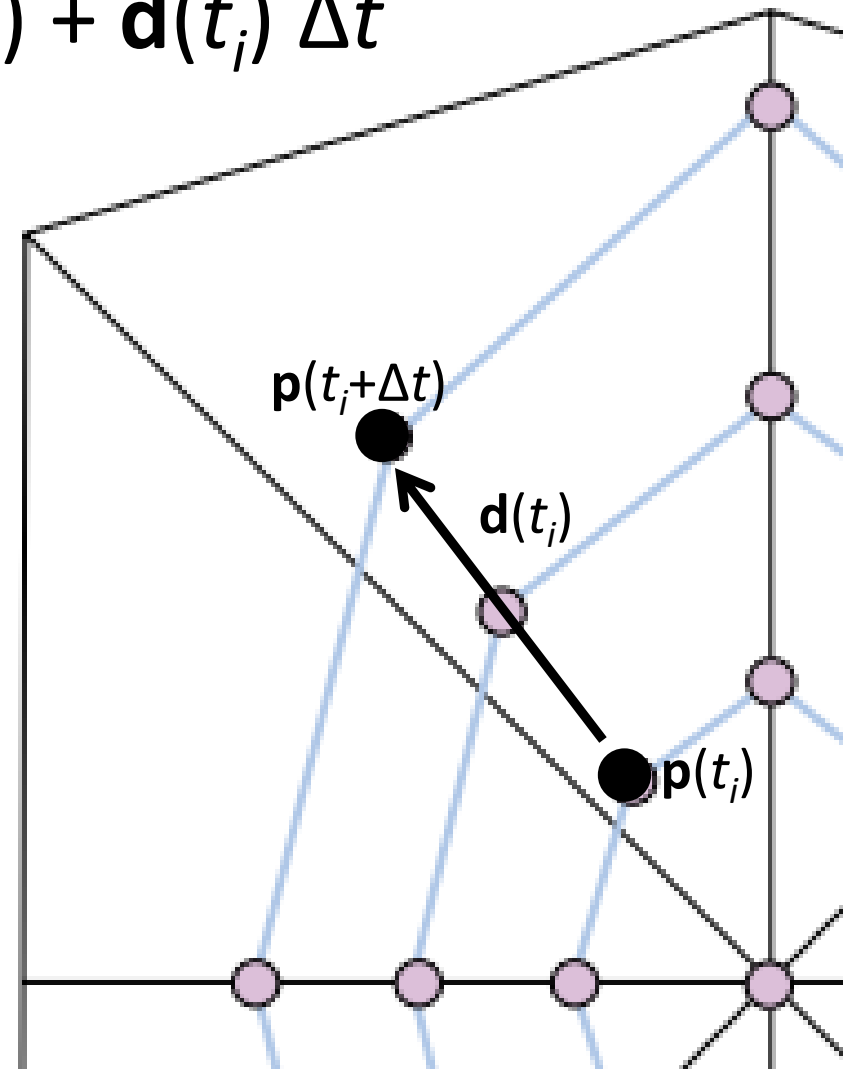




Fire Propagation

$$\mathbf{p}(t_i + \Delta t) = \mathbf{p}(t_i) + \mathbf{d}(t_i)\,\Delta t$$

- $\mathbf{p}(t_i + \Delta t)$ – next point
- $\mathbf{p}(t_i)$ – initial point
- $\mathbf{d}(t_i)$ – direction tangent to surface
- Δt – change in time



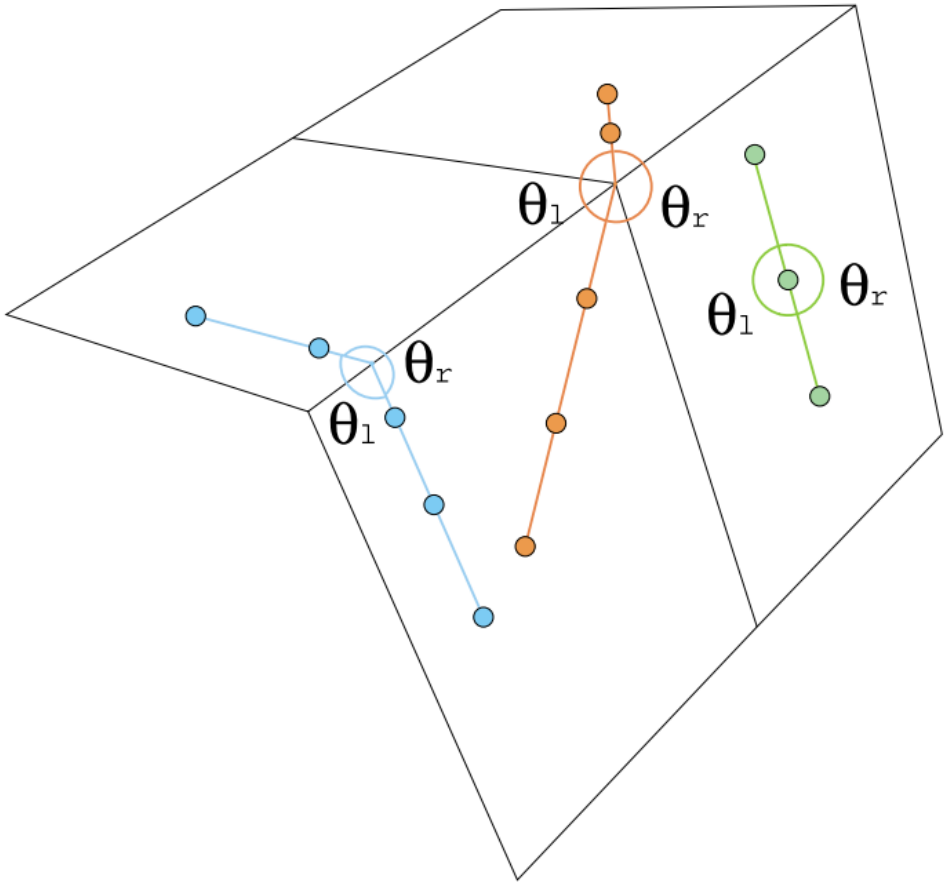
Fire Propagation

$$\mathbf{p}(t_i + \Delta t) = \mathbf{p}(t_i) + \mathbf{d}(t_i)\,\Delta t$$

- 3 Cases
  - $\mathbf{p}(t_i)$ and $\mathbf{p}(t_i + \Delta t)$ lie on the same face
  - $\mathbf{p}(t_i) \rightarrow \mathbf{p}(t_i + \Delta t)$ crosses an edge
  - $\mathbf{p}(t_i) \rightarrow \mathbf{p}(t_i + \Delta t)$ crosses a vertex

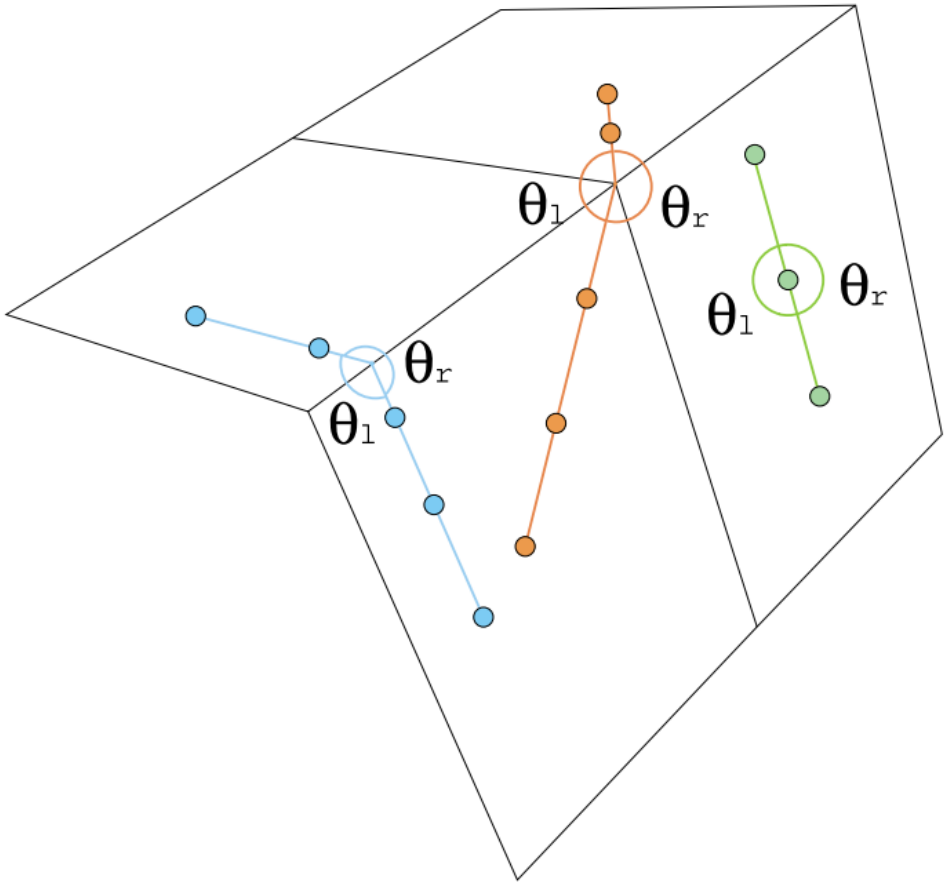
Fire Propagation

- $\mathbf{p}(t_i)$ and $\mathbf{p}(t_i + \Delta t)$ lie on the same face
  - Trivial



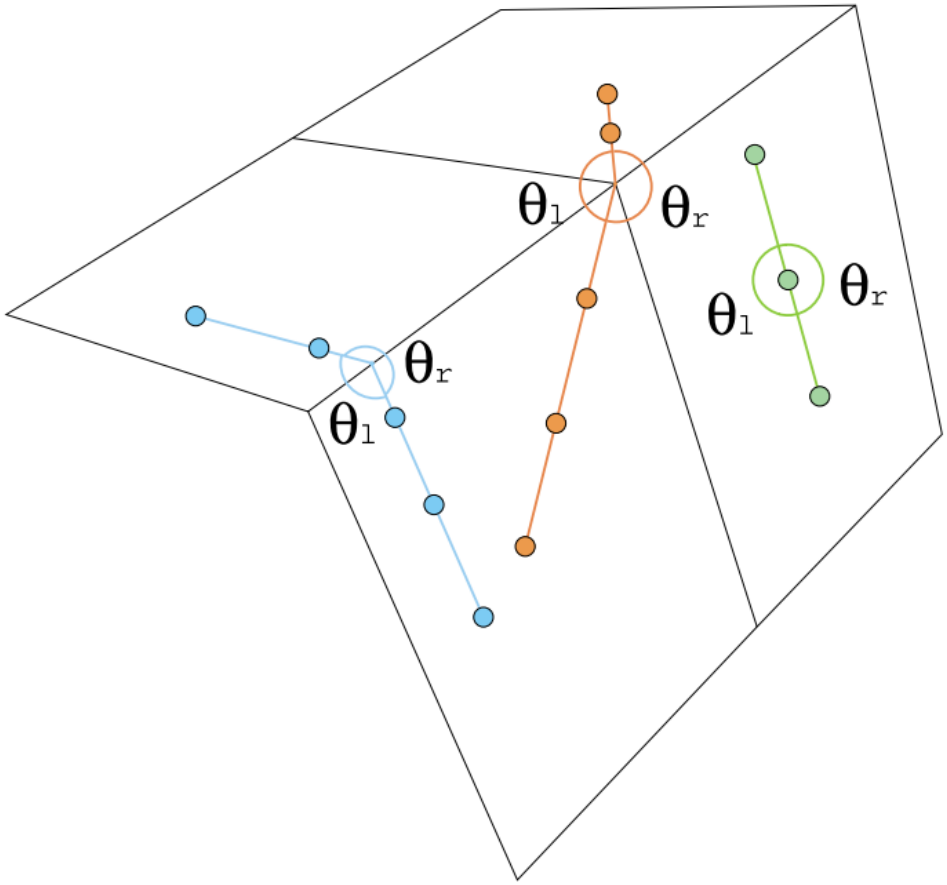
Fire Propagation

- $\mathbf{p}(t_i) \rightarrow \mathbf{p}(t_i + \Delta t)$ crosses an edge
  - Rotate $\mathbf{d}(t_i)$ around the edge by the angle between the surface normals of the neighboring faces



Fire Propagation

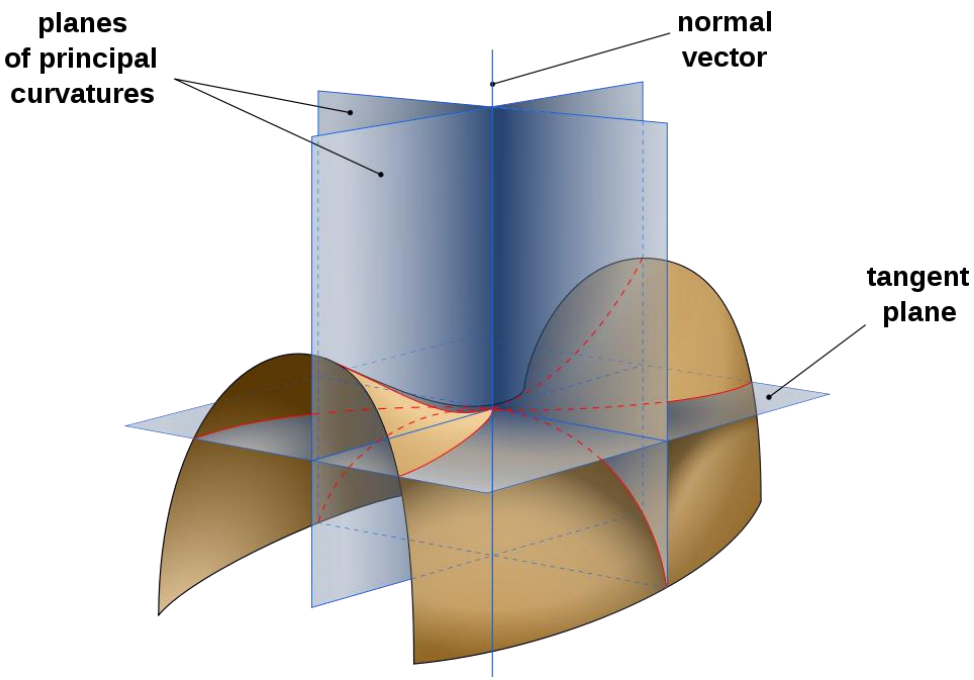
- $\mathbf{p}(t_i) \rightarrow \mathbf{p}(t_i + \Delta t)$ crosses a vertex
  - Calculate tangent so that resulting directions have equal left and right curve angles



Fire Propagation

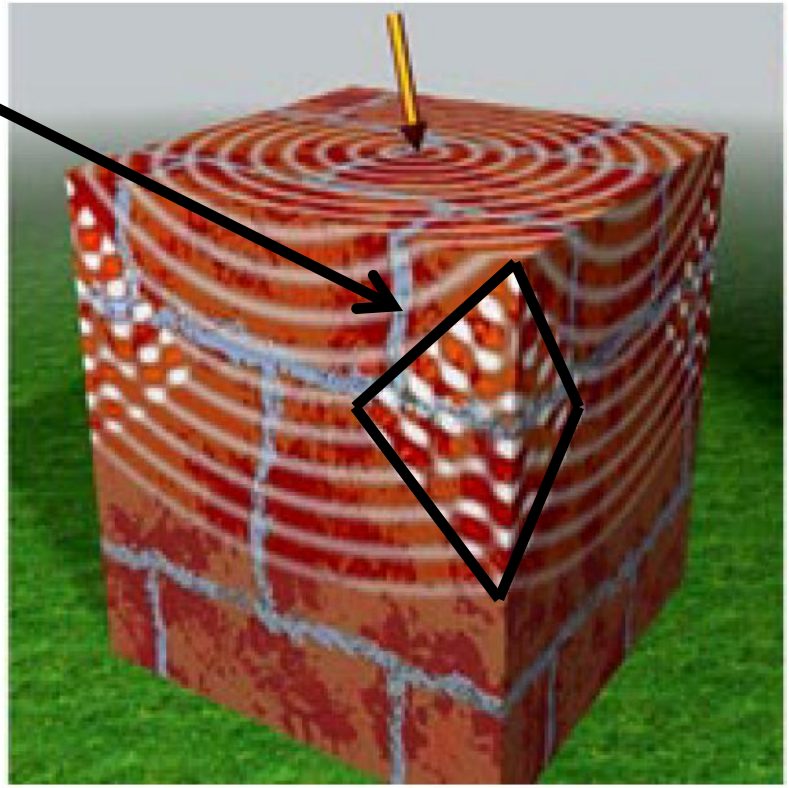
- Problems arise when front passes over odd geometry

Hyberbolic point



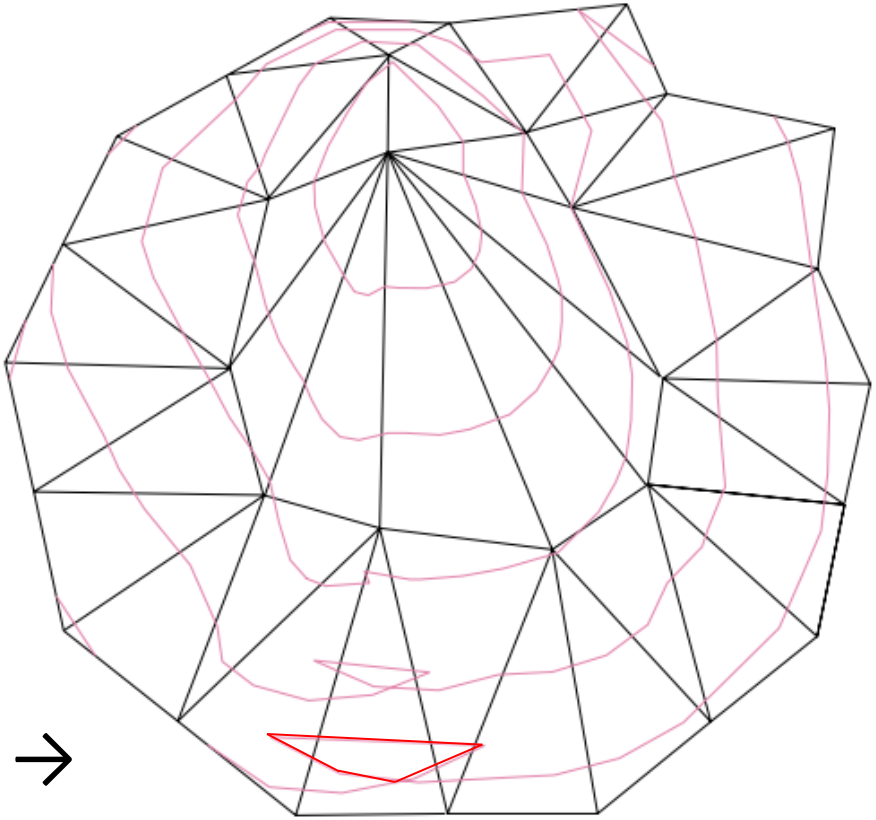
Interference

Conjugate point



Fire Propagation

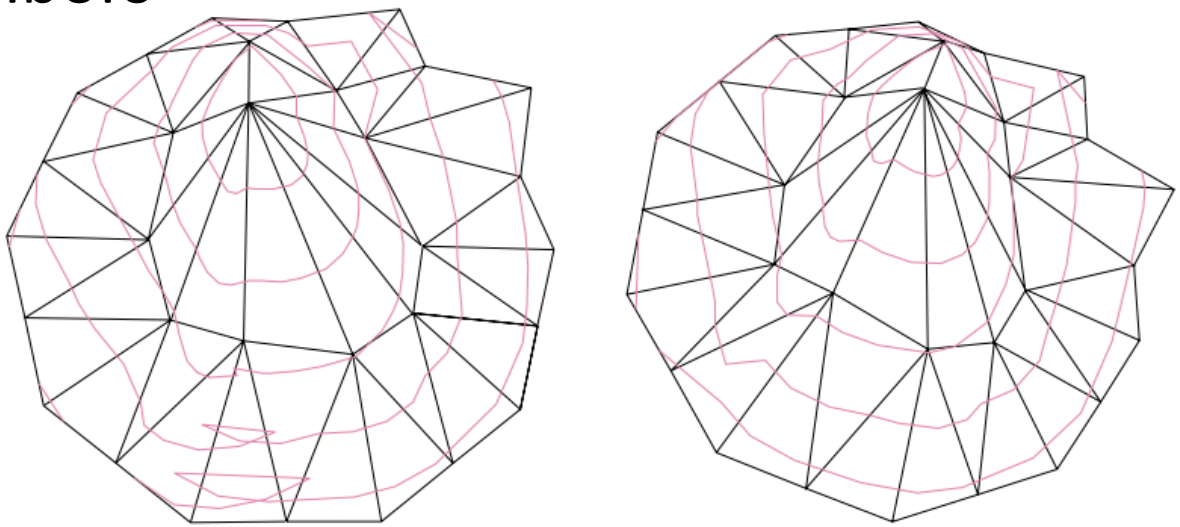
- Problems arise when front passes over odd geometry



Swallow-tail effect →

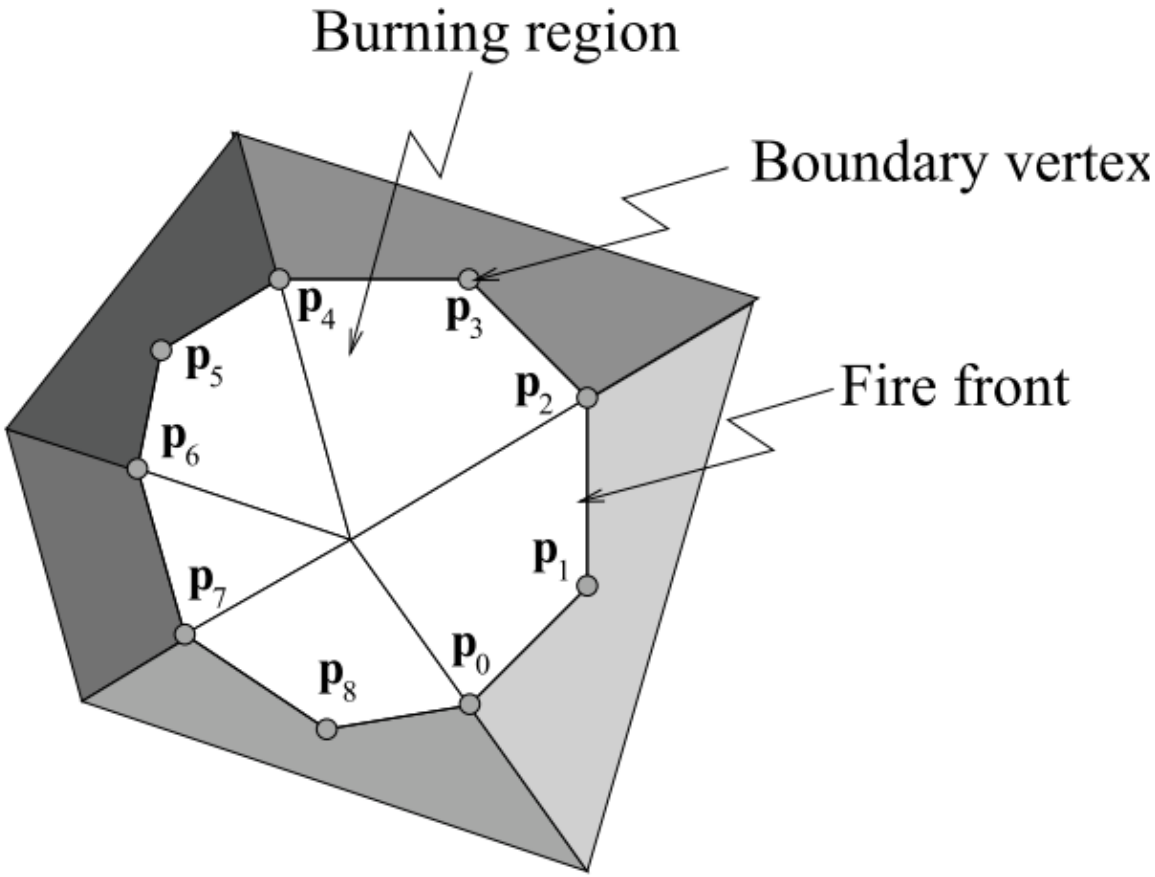
Fire Propagation

- Fix swallow-tails
  - Maintain ordered list of points on the front
  - Remove points that have a large difference in their tangent direction when compared to their neighbors



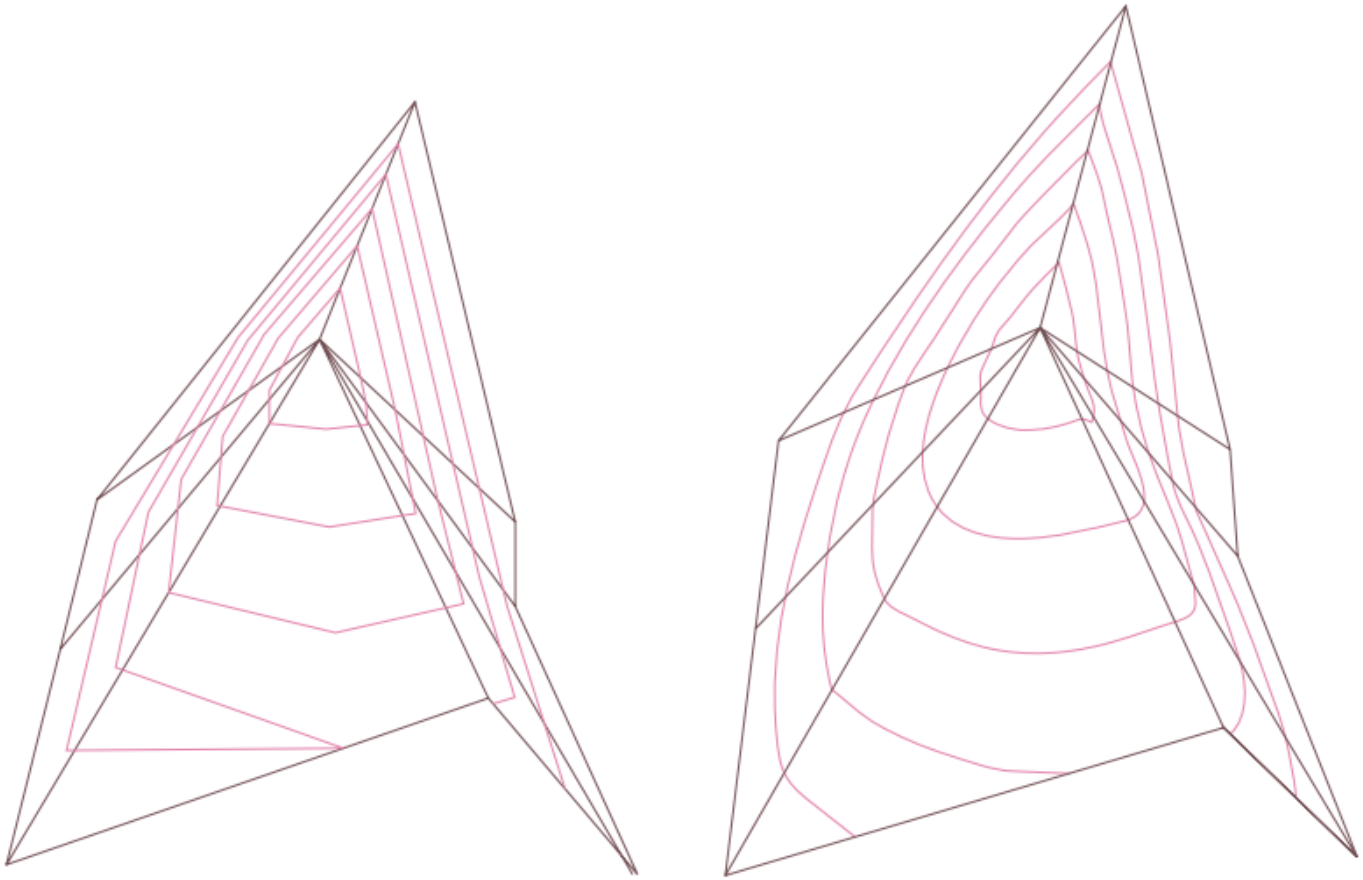
Fire Propagation

- Keep front on surface



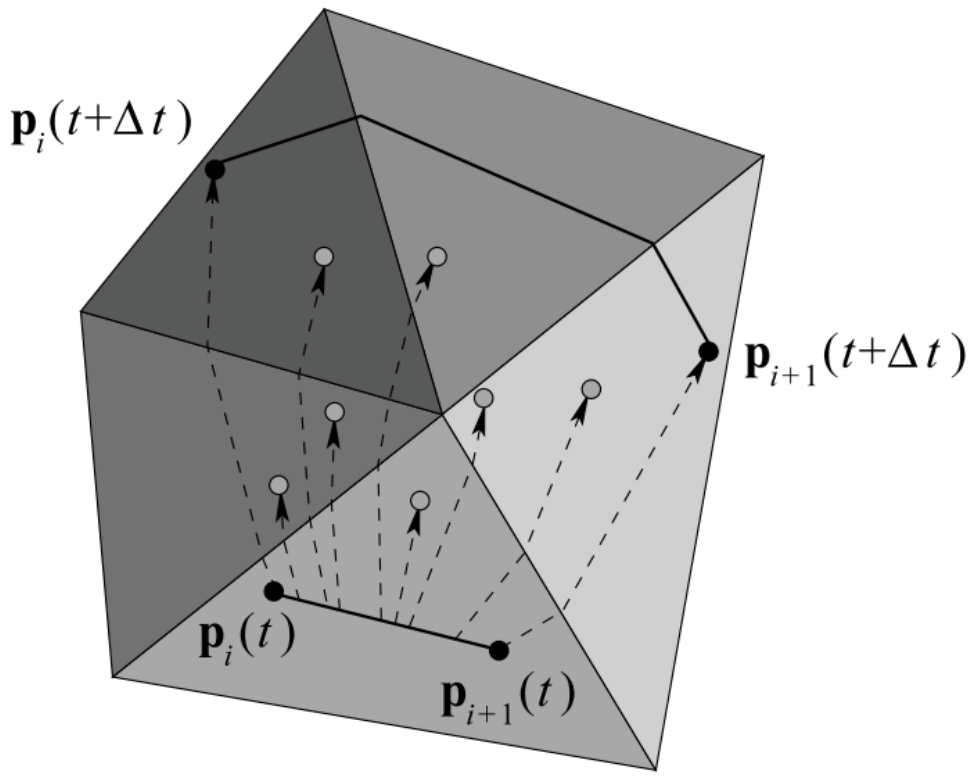
Fire Propagation

- As front moves, adaptively add/remove points



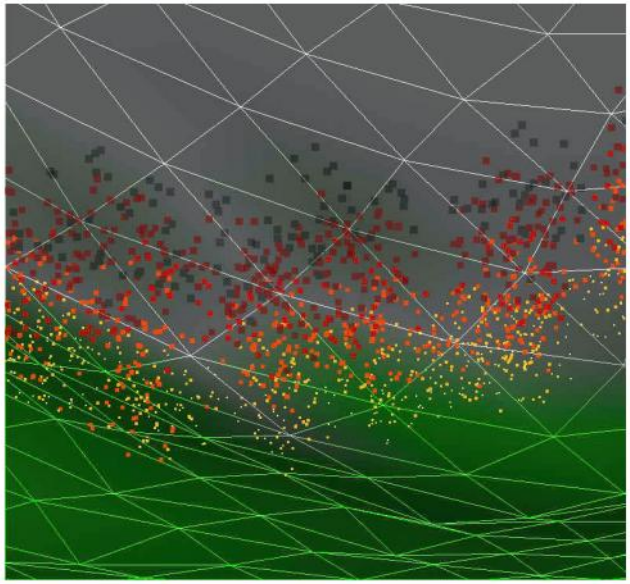
Fire Particles

- Deposit particle emitters as the front moves
- Particles are released based on the state of the emitter
  - Fuel density
  - Temperature



Fire Particles

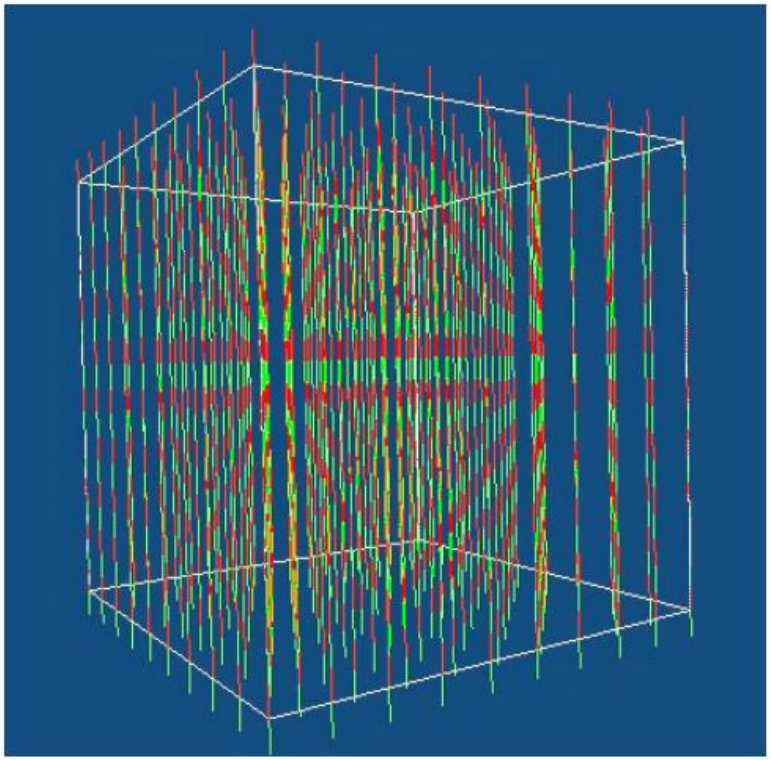
- Standard particles
  - Position
  - Velocity
  - No collision
- Additional attributes
  - Lifetime
  - Size
  - Temperature
  - Color
  - Transparency



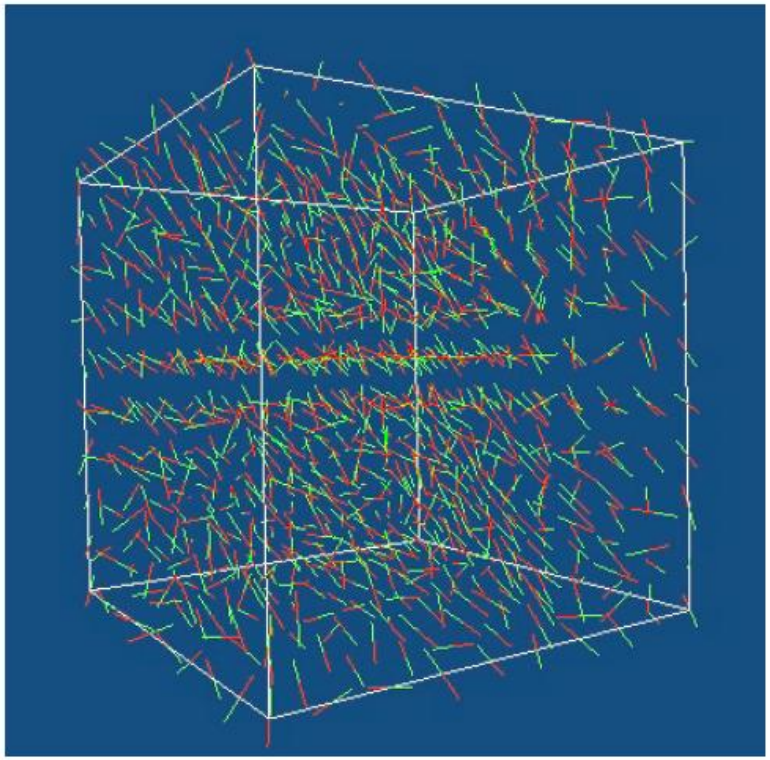
Wind Field Model

- How to control front propagation and particle movement?
- Vector field describing wind direction and speed over time

Wind Field Model



Large upward field



Random, turbulent field

Wind Field & Front Propagation

$$\mathbf{v}(t) = \mathbf{d}(t)(1 + k_{wind}\,\mathbf{d}(t) \bullet \mathbf{w}(\mathbf{p}(t),t))$$

- Recall
  - $\mathbf{p}(t)$ – initial point
  - $\mathbf{d}(t)$ – direction tangent to surface
- $\mathbf{v}(t)$ – velocity of propagation
- k_{wind} – coefficient of wind influence
- $\mathbf{w}(\mathbf{p},t)$ – wind field at point $\mathbf{p}$ and time t

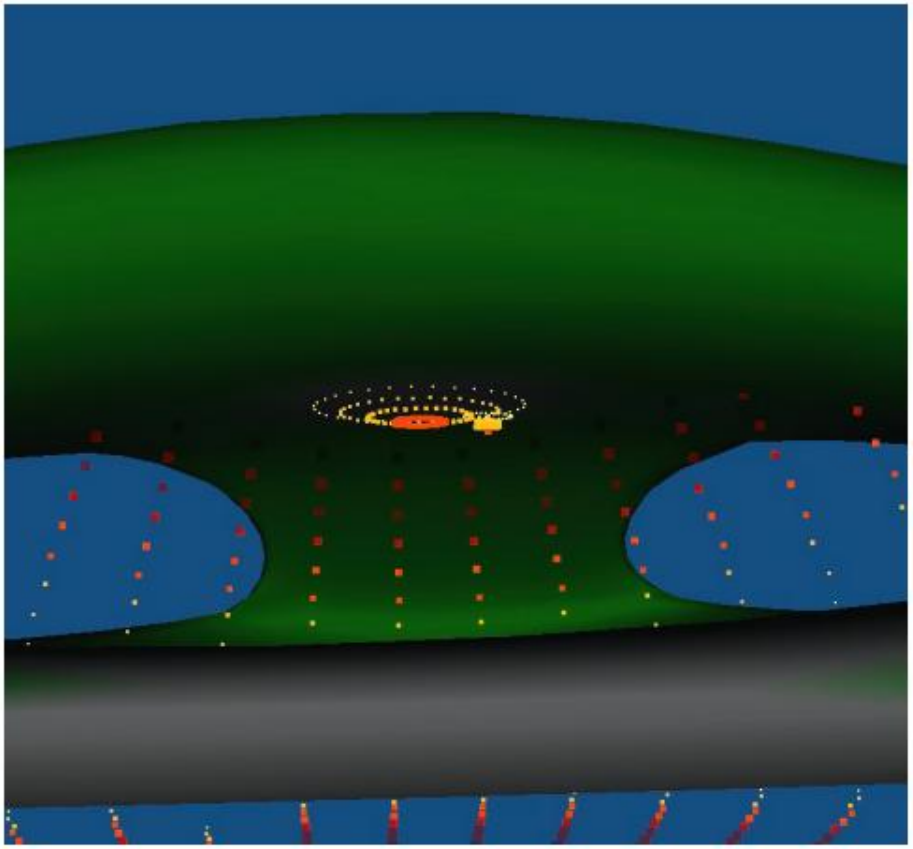
Effect of Terrain Slope

$$\mathbf{v}(t) = \mathbf{d}(t)(1 + k_{wind}\,\mathbf{d}(t) \bullet \mathbf{w}(\mathbf{p}(t),t) - k_{slope}\,\mathbf{d}(t) \bullet \mathbf{g})$$

- Recall
  - $\mathbf{p}(t)$ – initial point
  - $\mathbf{d}(t)$ – direction tangent to surface
  - $\mathbf{v}(t)$ – velocity of propagation
  - k_{wind} – coefficient of wind influence
  - $\mathbf{w}(\mathbf{p},t)$ – wind field at point $\mathbf{p}$ and time t
- k_{slope} – coefficient of slope influence
- $\mathbf{g}$ – gravity vector

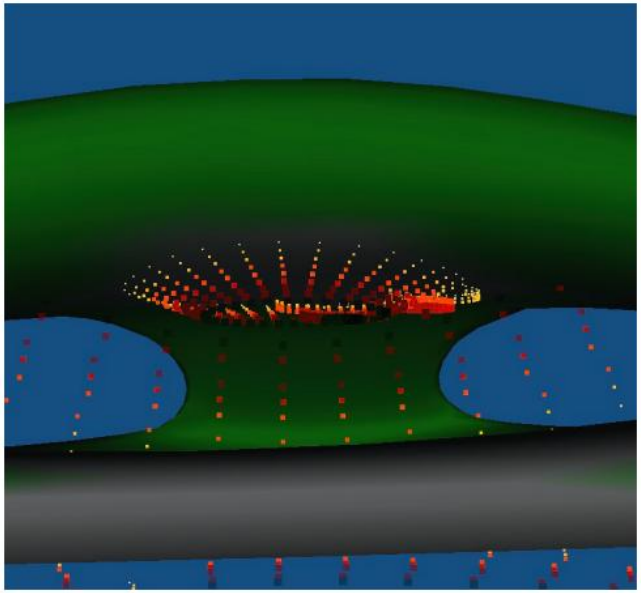
Multiple Fire Fronts

- What if flames reach overhanging geometry?



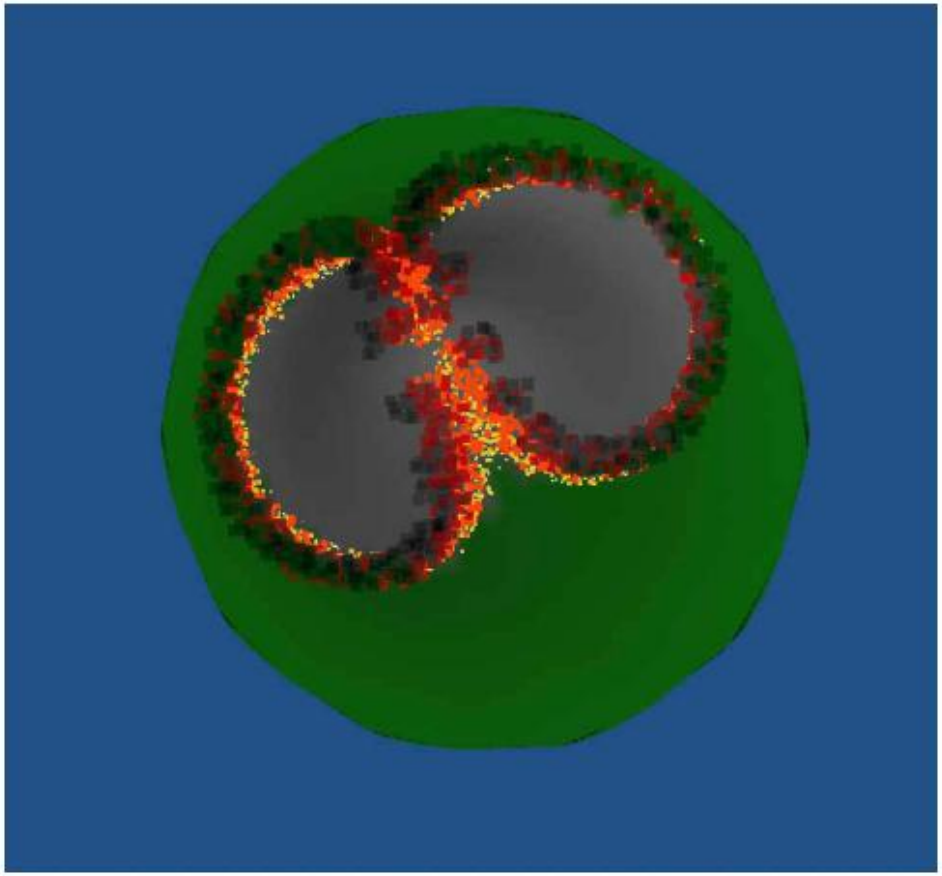
Multiple Fire Fronts

- Approximate geometry with rectangular grid
- If collision detected, move particle out of the object
- If particle is hot enough, start new fire



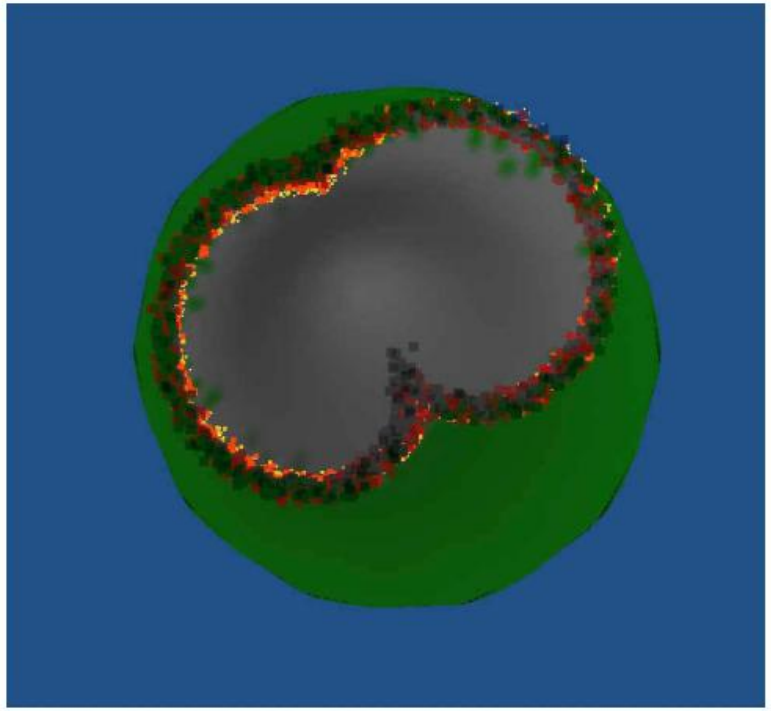
Fire Front Merging

- Avoid “double burning”



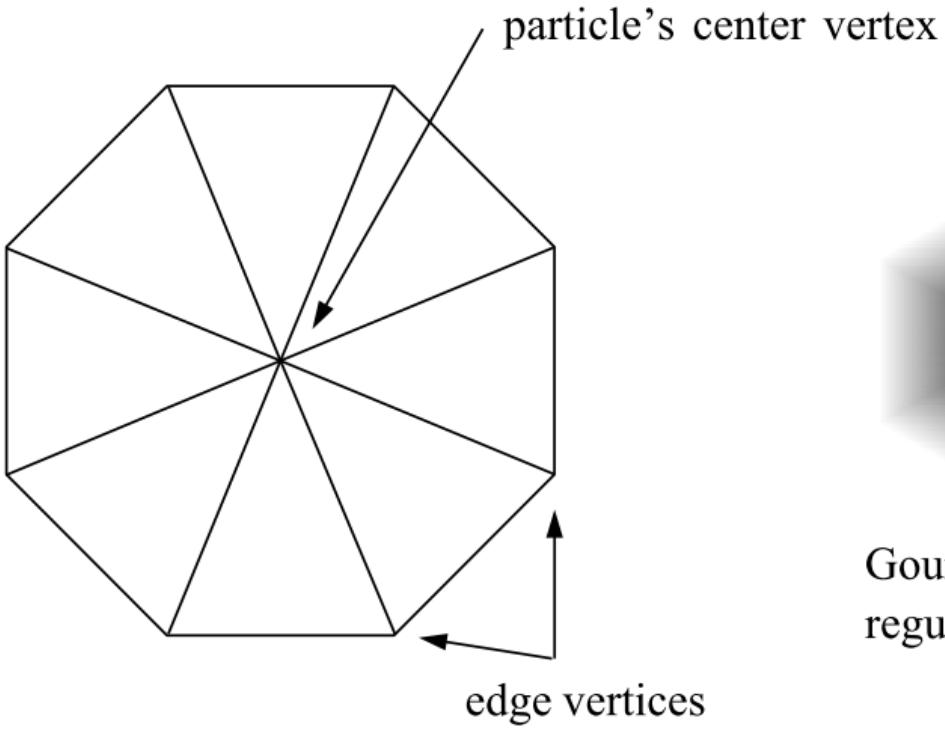
Fire Front Merging

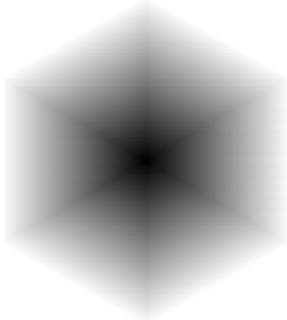
- 2 approaches
  - List of triangle IDs for each front
  - When a triangle is completely burnt, deactivate its front particles



Enhanced Particles

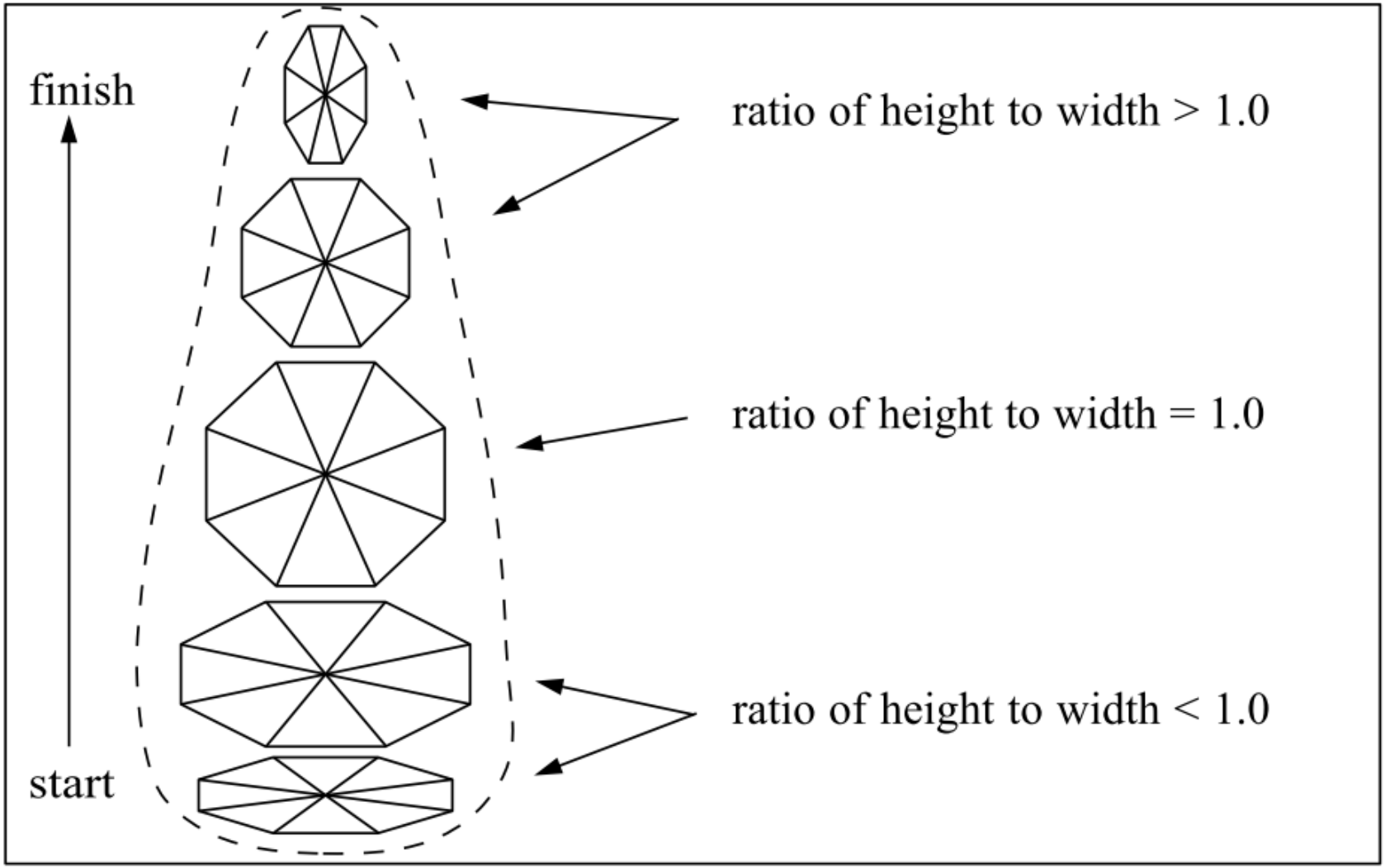
- Alternative to simple, individual fire particles
- Use polygons instead of point particles





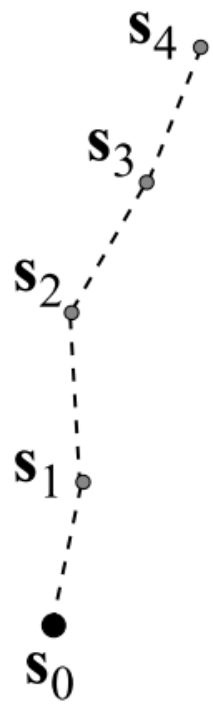
Gouraud shaded
regular hexagon

Enhanced Particles



Flame Skeletons

- Another alternative to simple, individual fire particles
- Represent a flame as a chain of connected particles

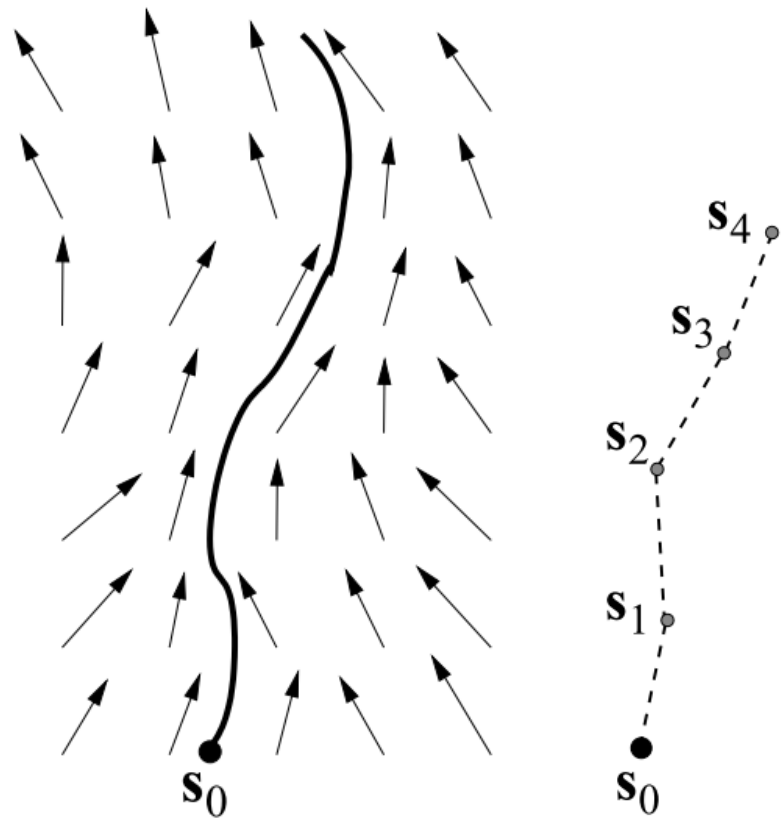


Flame Skeletons

- Placed randomly just like particle emitters
- Shaped based on wind field

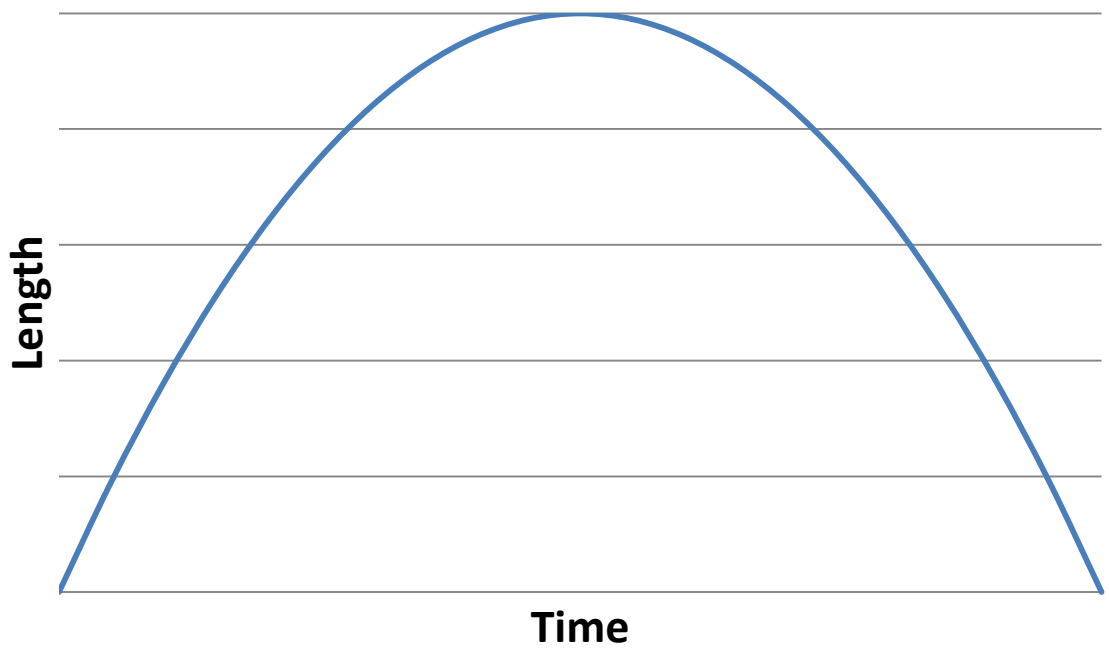
$$\mathbf{s}_i = \mathbf{s}_{i-1} + \frac{l(t)}{n}\mathbf{V}(\mathbf{s}_{i-1})$$

l(t) – length of the skeleton
n – number of segments
$\mathbf{V}(s_{i-1})$ – wind velocity



Flame Skeletons

- Length grows/shrinks with time
- Quadratic function starting and ending at 0



Flame Skeletons

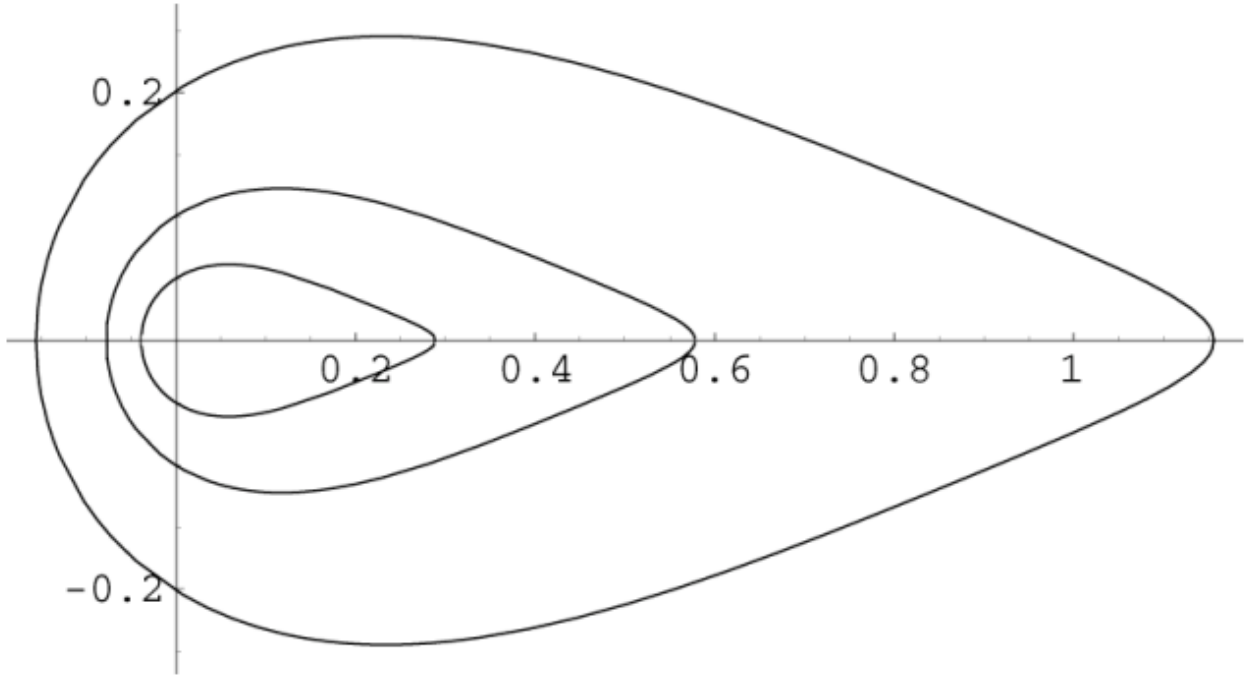
- Turbulent fire can yield detached flames
- Allow the root of the skeleton to leave the surface

$$\mathbf{s}_0(t + \Delta t) = \mathbf{s}_0(t) + \Delta t\, \mathbf{V}(\mathbf{s}_0(t), t)$$

$\mathbf{s}_0$ – root of the skeleton
$\mathbf{V}(\mathbf{s}_0(t),t)$ – wind field velocity

Flame Skeletons

- Use an implicit surface when rendering
- With n = 4, use 3 isosurfaces



P. Beaudoin, S. Paquet, P. Poulin. "Realistic and Controllable Fire Simulation"

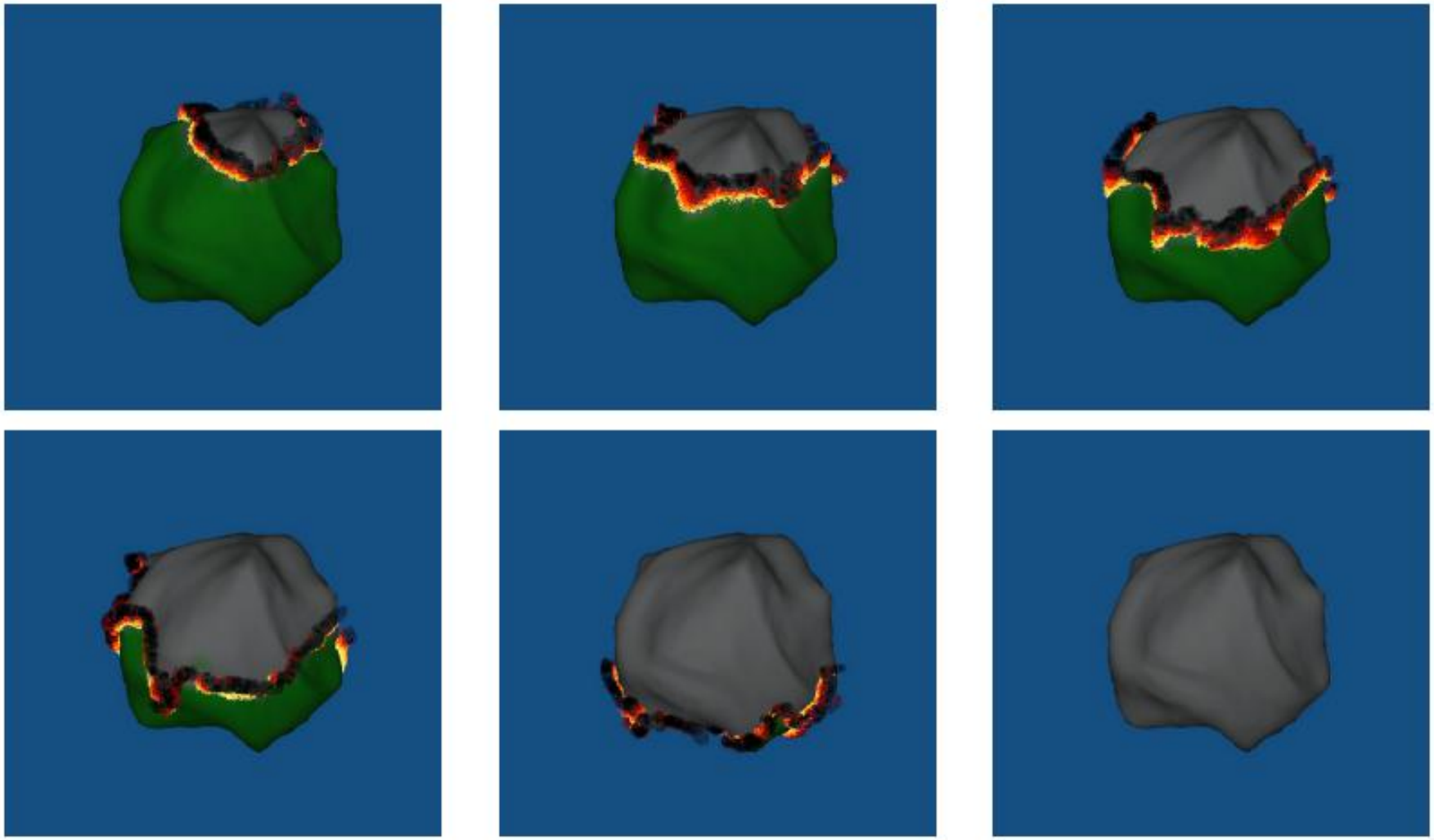
Flame Skeletons

- Use marching cubes to combine multiple flames
  - Evaluate intensity of fire at each cell in a regular grid
  - For each flame, only consider the neighboring cells

Flame Skeletons

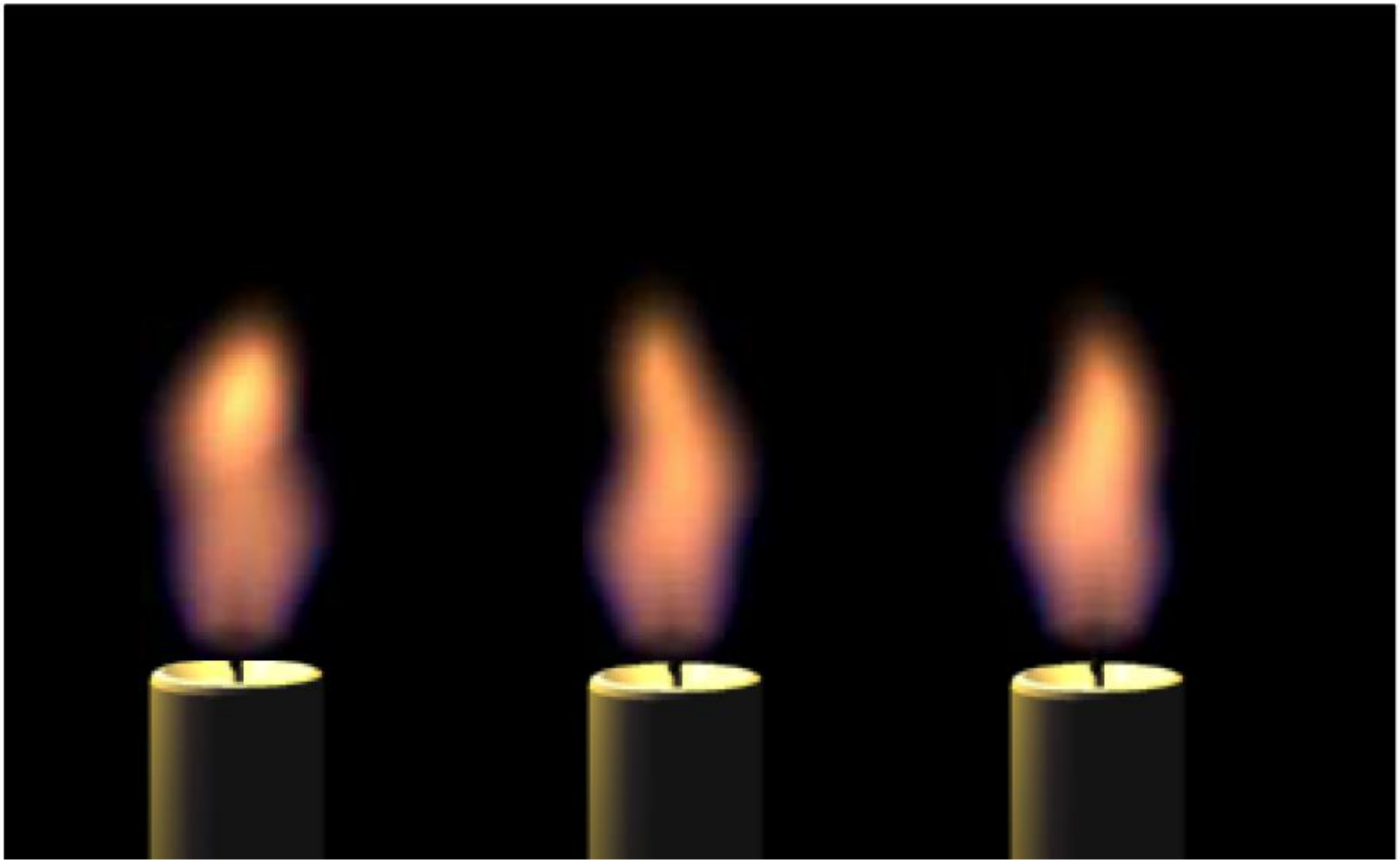
- 2 approaches to rendering
  - Ray tracing
  - Rasterize from back to front

Results



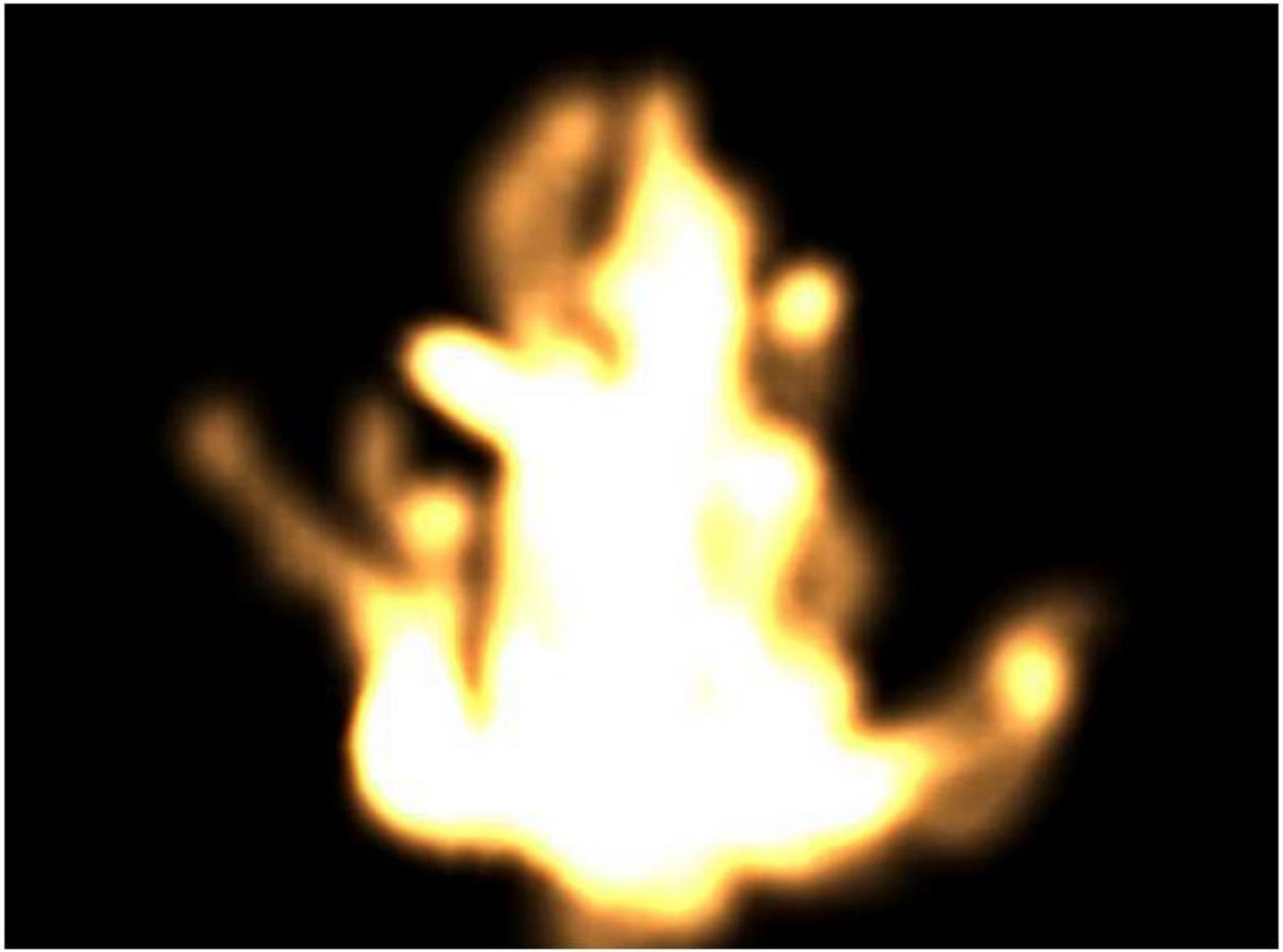
H. Lee, L. Kim, M. Meyer. "Meshes on Fire"

Results



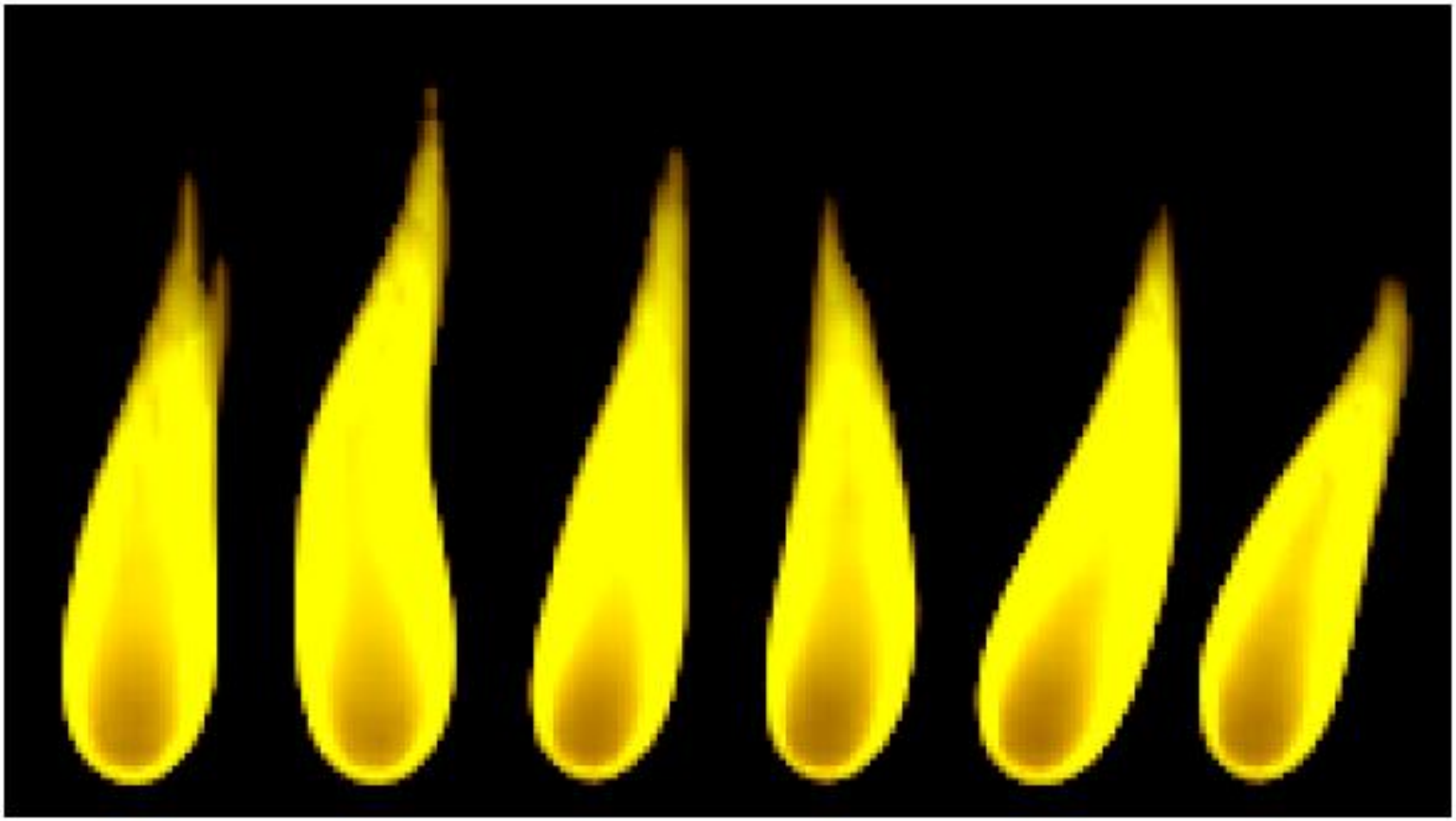
C. Perry, R. Picard. "Synthesizing Flames and their Spreading"

Results



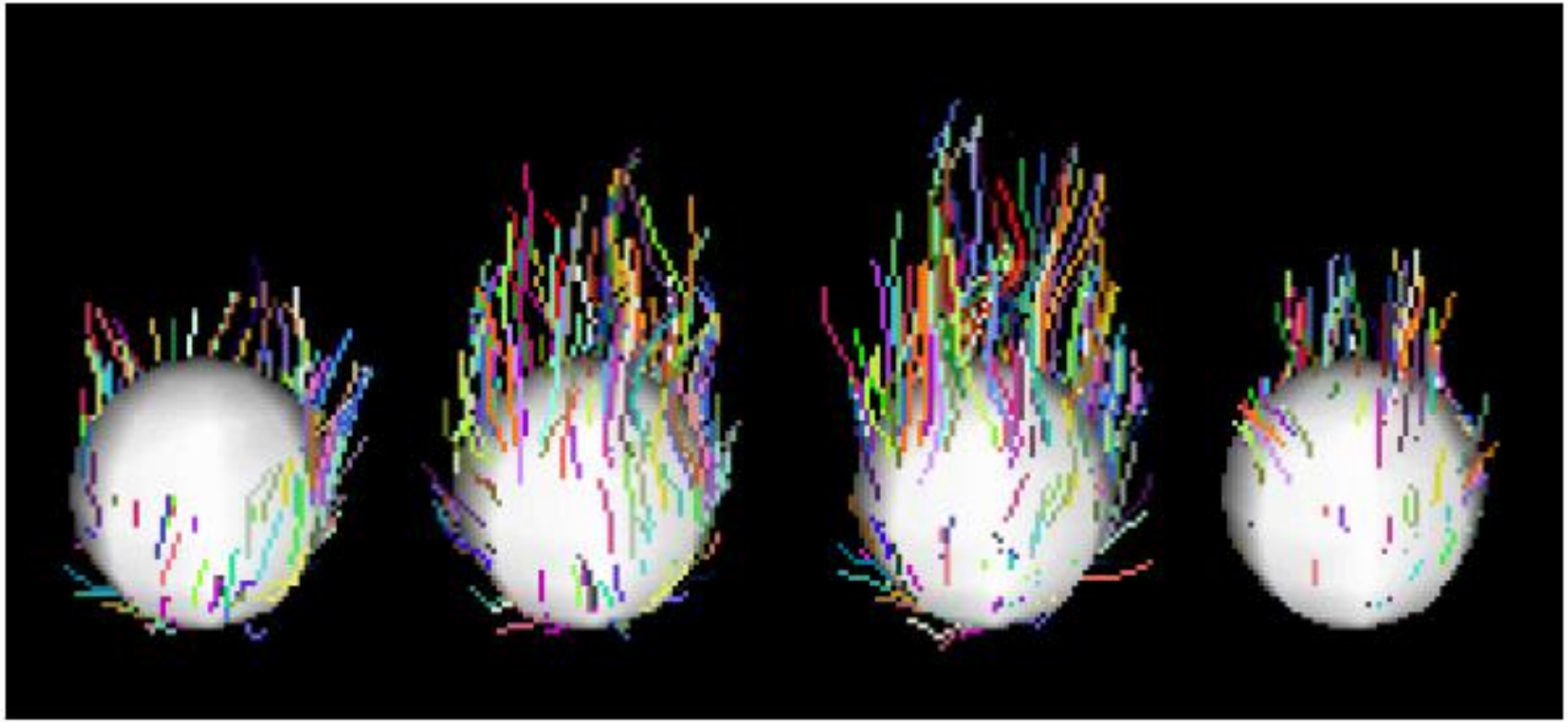
C. Perry, R. Picard. "Synthesizing Flames and their Spreading"

Results



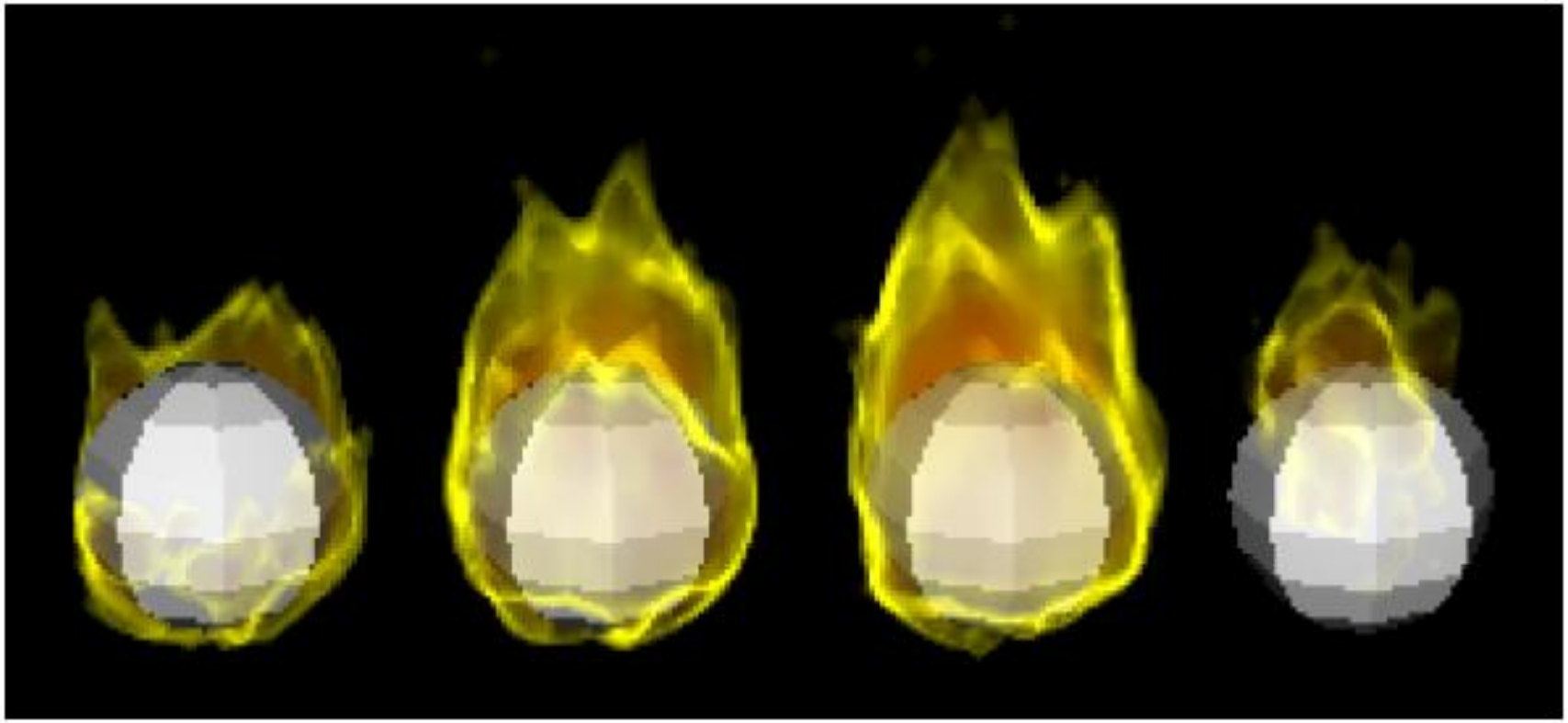
P. Beaudoin, S. Paquet, P. Poulin. "Realistic and Controllable Fire Simulation"

Results



P. Beaudoin, S. Paquet, P. Poulin. "Realistic and Controllable Fire Simulation"

Results



P. Beaudoin, S. Paquet, P. Poulin. "Realistic and Controllable Fire Simulation"

References

- H. Lee, L. Kim, M. Meyer. "Meshes on Fire". EG Workshop on Computer Animation and Simulation, p.75-84, 2000.
- C. Perry, R. Picard. "Synthesizing Flames and their Spreading". Proceedings of the Fifth Eurographics Workshop on Animation and Simulation, p.1-14, 1994.
- P. Beaudoin, S. Paquet, P. Poulin. "Realistic and Controllable Fire Simulation". Graphics Interface 2001, p.159-166, 2001.
- K. Polthier and M. Schmies. Straightest geodesics on polyhedral surfaces. Mathematical Visualization, p.135–150, 1998.
- K. Polthier and M. Schmies. Geodesic flow on polyhedral surfaces. Proceedings of Eurographics-IEEE Symposium on Scientific Visualization ’99, 1999.
- W. T. Reeves. Particle systems – a technique for modeling a class of fuzzy objects. ACM Trans. Graphics, p.91–108, April 1983.

Questions?