VGP353 – Week 7

- Agenda:
  - Quiz #3
  - Generating shadow volume geometry
    - Side-trip into mesh data structures
    - Using a *real* mesh data structure to generate the shadow volume geometry
  - Assignments...

Shadow Volume Geometry

- Generating shadow volume geometry directly from raw vertex data is *hard*
  - Clearly some data structure is needed to make the work easier
- What features must this data structure have?

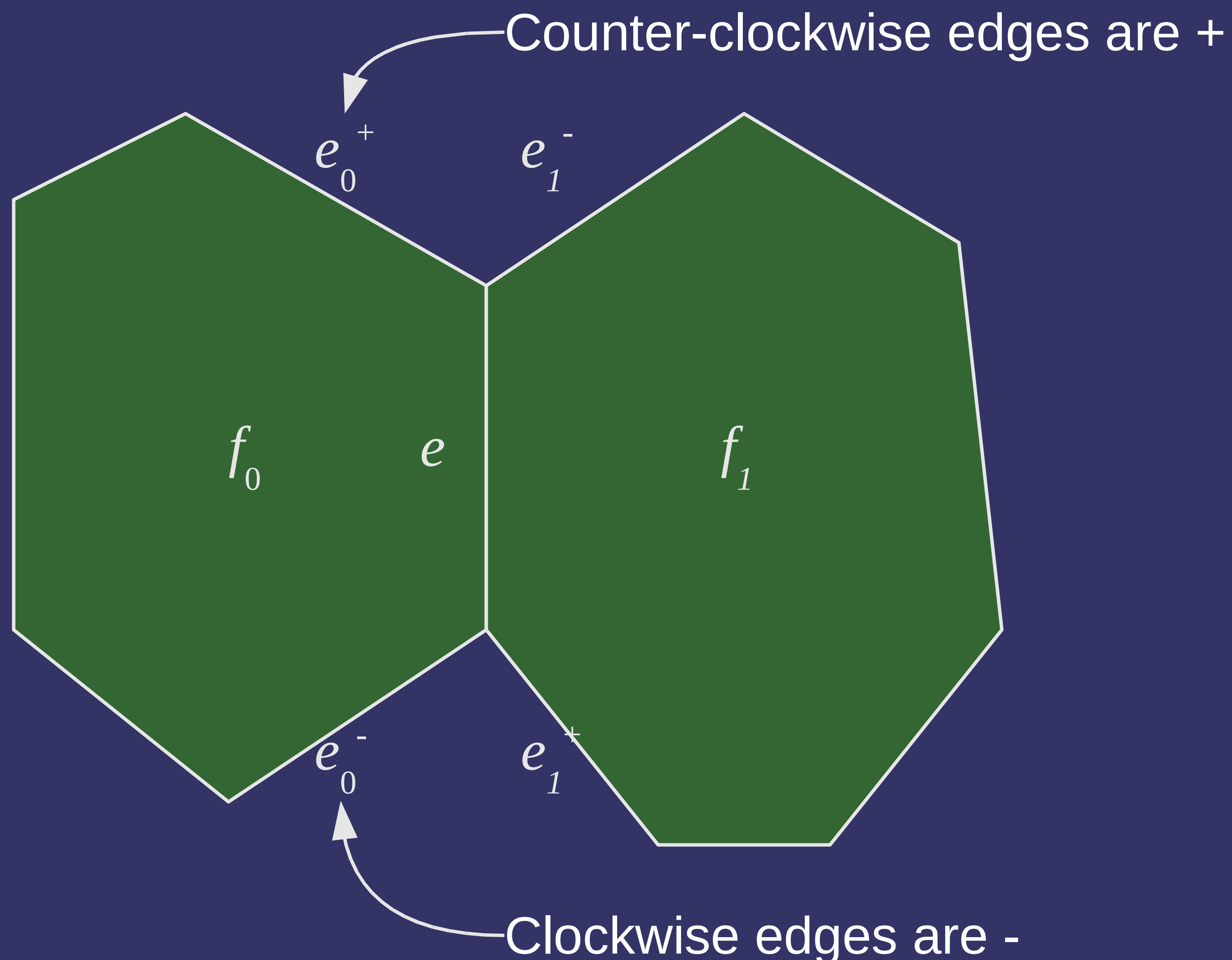
Shadow Volume Geometry

- Generating shadow volume geometry directly from raw vertex data is *hard*
  - Clearly some data structure is needed to make the work easier
- What features must this data structure have?
  - Iterate over each edge in the mesh *exactly once*
  - Access to each polygon sharing an edge
  - Access to neighboring edges in each polygon
    - This is so that normals can be calculated
- Does such a magical data structure exist?

Winged-Edge Mesh

- The *original* mesh structure to store connectivity information
- As the name implies, the focus is the *edge*
  - Each vertex stores a pointer to one of the edges "radiating" from it
  - Each polygon stores a pointer to one of its edges
  - Each edge has 8 pointers:
    - Pointers to each of its vertices (2)
    - Pointers to each of its polygons (2)
    - Pointers to each of its connecting edges (4)

Winged-Edge Mesh



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Winged-Edge Mesh

- Desirable mesh representation properties:
  - Ease of manipulation: adding and removing data should not be too expensive
  - Scalability: May want to trade data size for performance per the needs of the application

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  - Ease of manipulation: adding and removing data should not be too expensive
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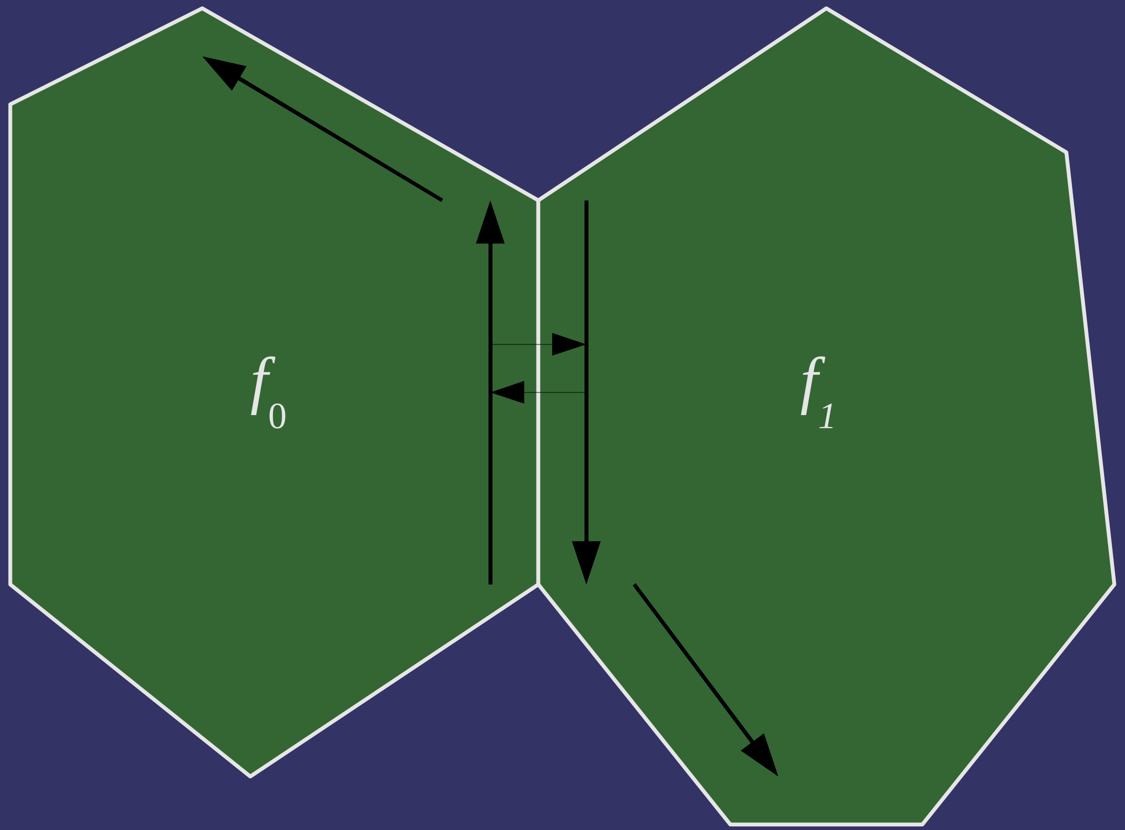
- Several common types of updates on WE meshes are *really* complicated to implement correctly

- Base winged-edge lacks the ability to iterate over the edges
- Base winged-edge has a *lot* of extra pointers that we will never use

Half-Edge Mesh

- Slight modification of winged-edge mesh:
  - Half-edge (HE) structures replace (full) edges
  - Each HE stores 4 pointers:
    - Pointer to starting vertex (1)
    - Pointer to polygon (1)
    - Pointer to counter-clockwise neighbor HE on the same polygon (1)
    - The “opposite” HE (1)
      - I call this the *sibling edge*
      - Other references call it *symmetric edge* or *pair edge*

Half-Edge Mesh



Half-Edge Mesh

```
struct half_edge {
    // Pointer to next counter-clockwise edge on same
    // polygon
    struct half_edge *next_ccw;

    // Pointer to matching edge on different polygon
    struct half_edge *sibling;

    // Pointer to the owning polygon
    struct polygon *p;

    // Pointer to next edge in global mesh edge list
    struct half_edge *next;

    // Pointer to starting vertex
    struct vertex *v;
};
```

Half-Edge Mesh

- If each HE only stores one vertex pointer, how do we get the other end?

Half-Edge Mesh

- If each HE only stores one vertex pointer, how do we get the other end?
  - The sibling edge stores a pointer to the other vertex
  - `e->v` and `e->sibling->v` make up the complete edge

Half-Edge Mesh

```
struct vertex {
    // Pointer an edge leaving this vertex
    struct half_edge *edge;

    // Pointer to position data for this vertex
    Vectormath::Aos::Vector4 *v;
};
```

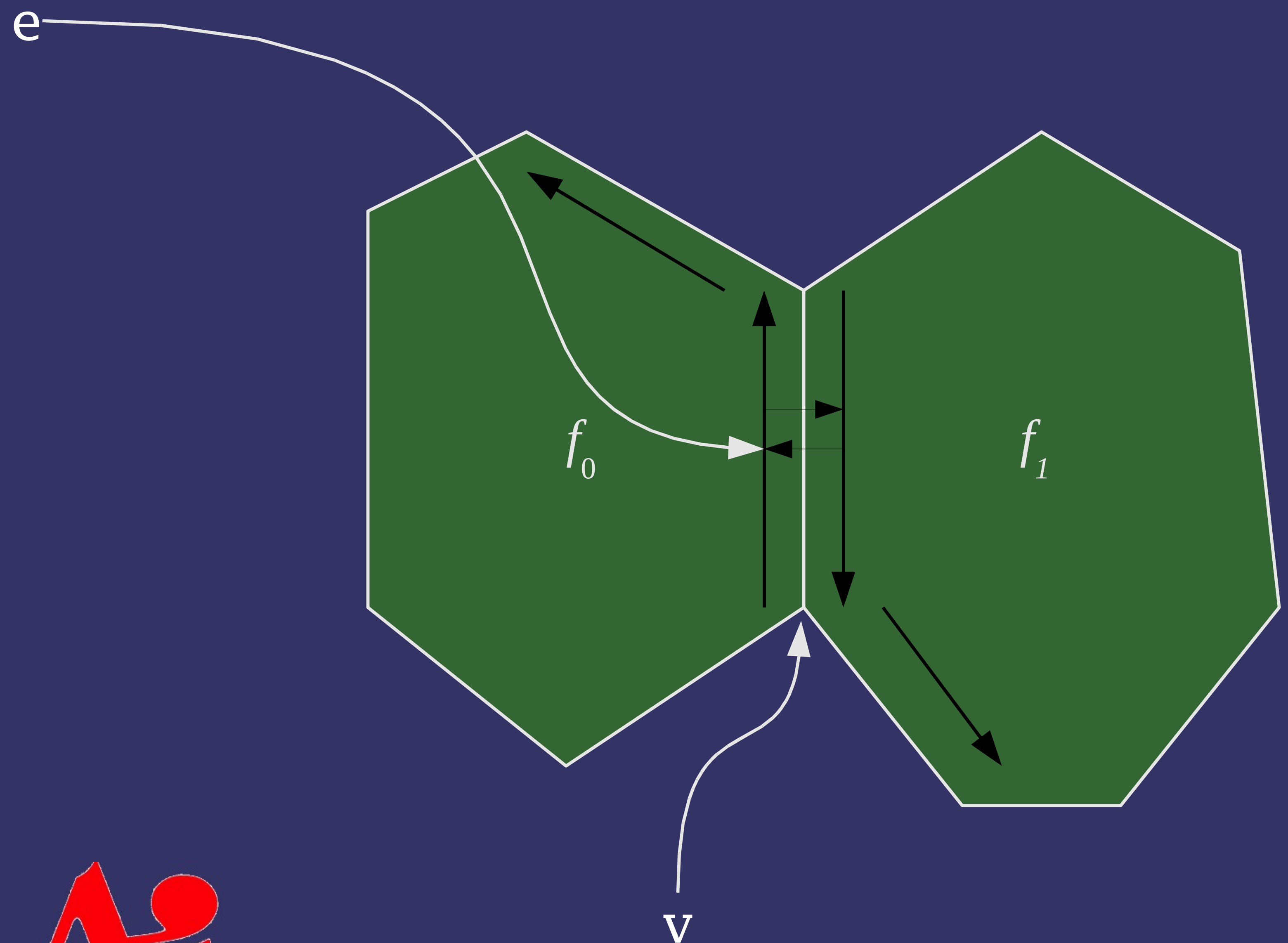
Half-Edge Mesh

- Given a vertex structure, how can we iterate all the edges that share that vertex?

```
half_edge *e = v->edge;
do {
    // Do real work here.

    // Iterate to next edge
    e = e->sibling->next_ccw;
} while (e != v->edge);
```

Half-Edge Mesh



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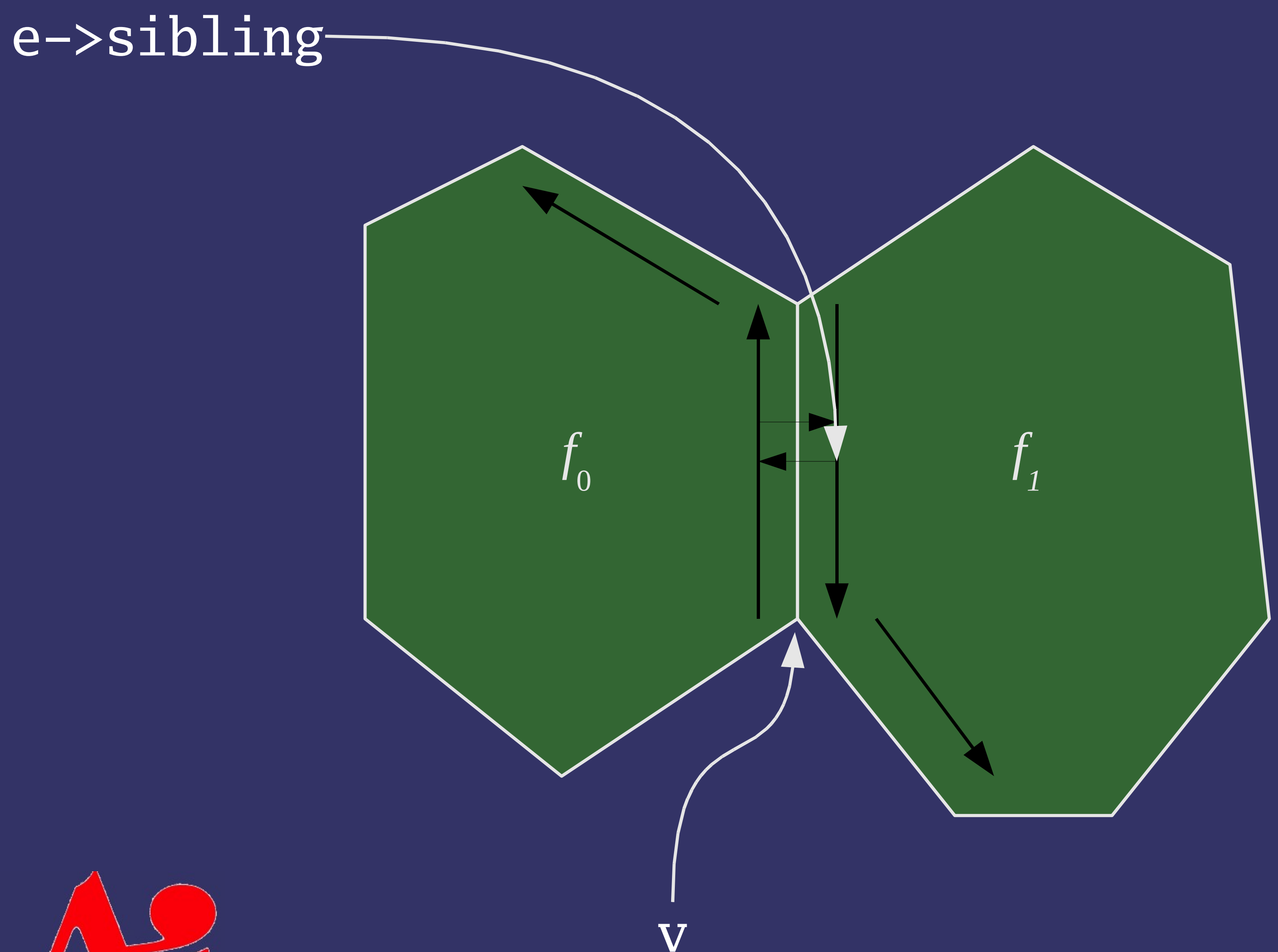

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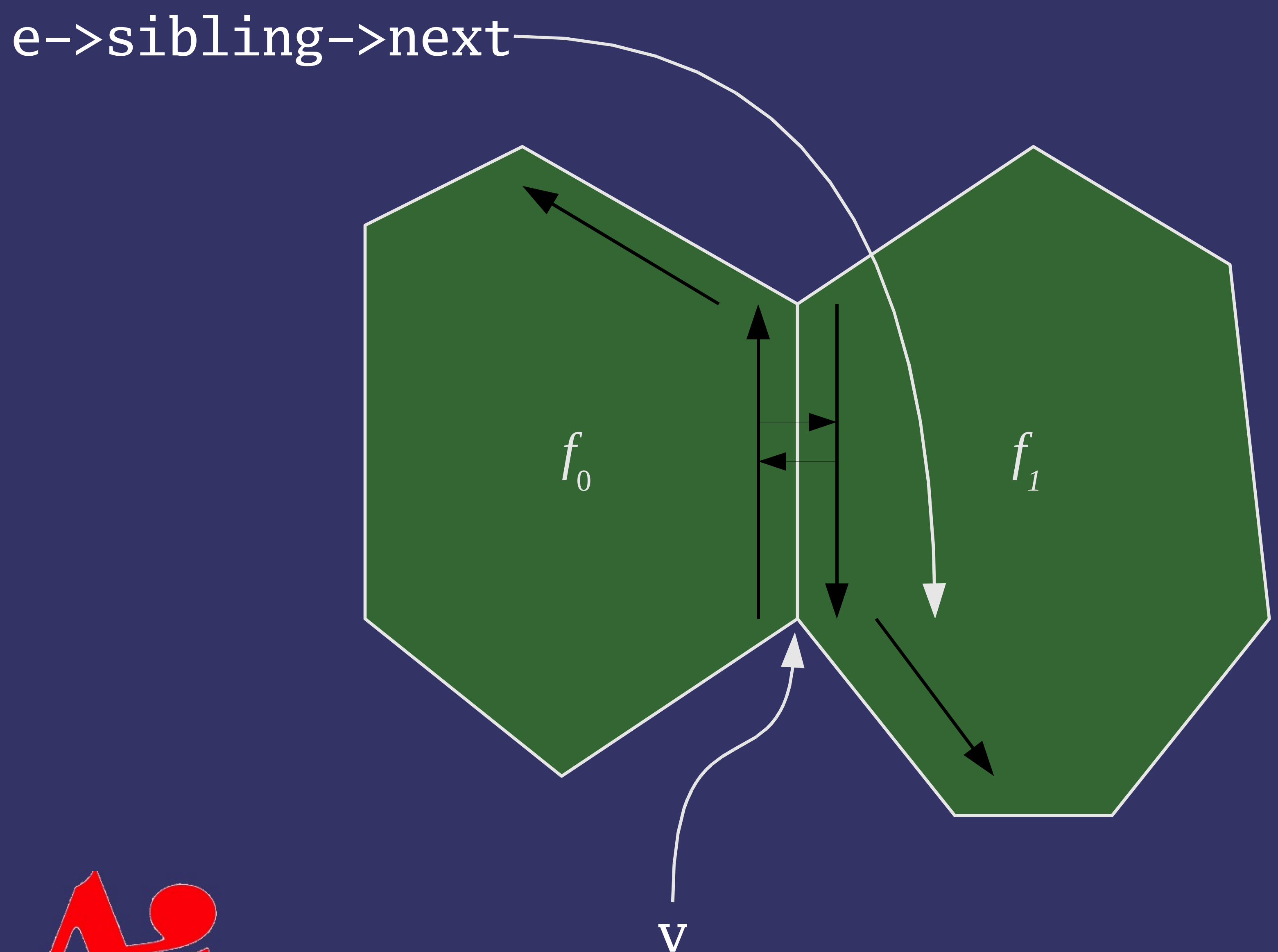
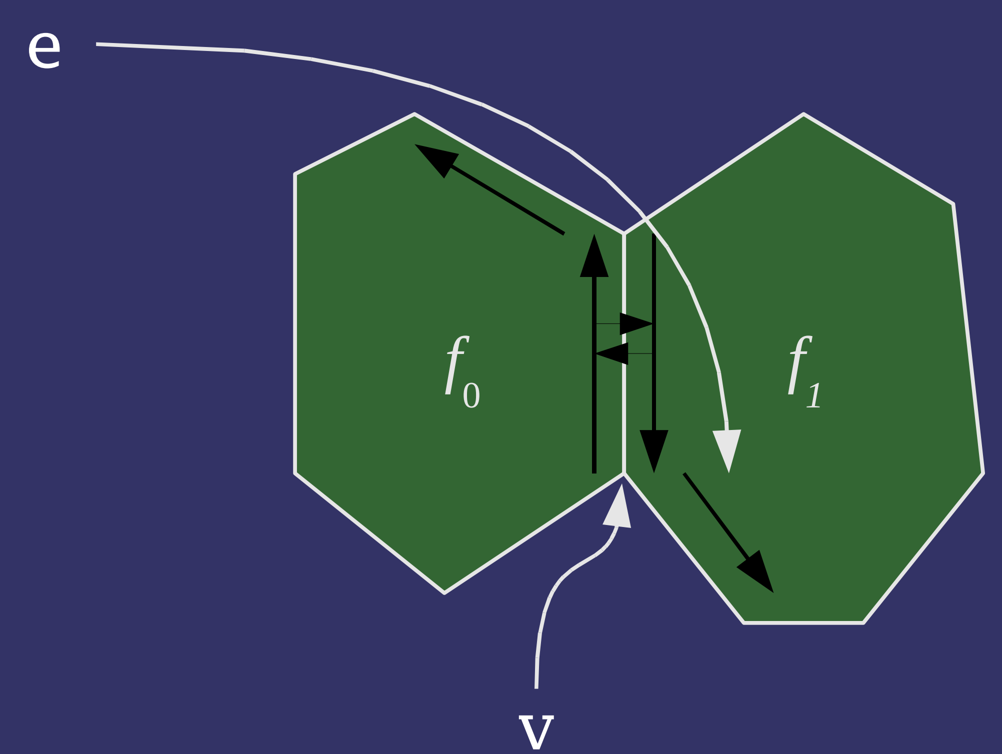


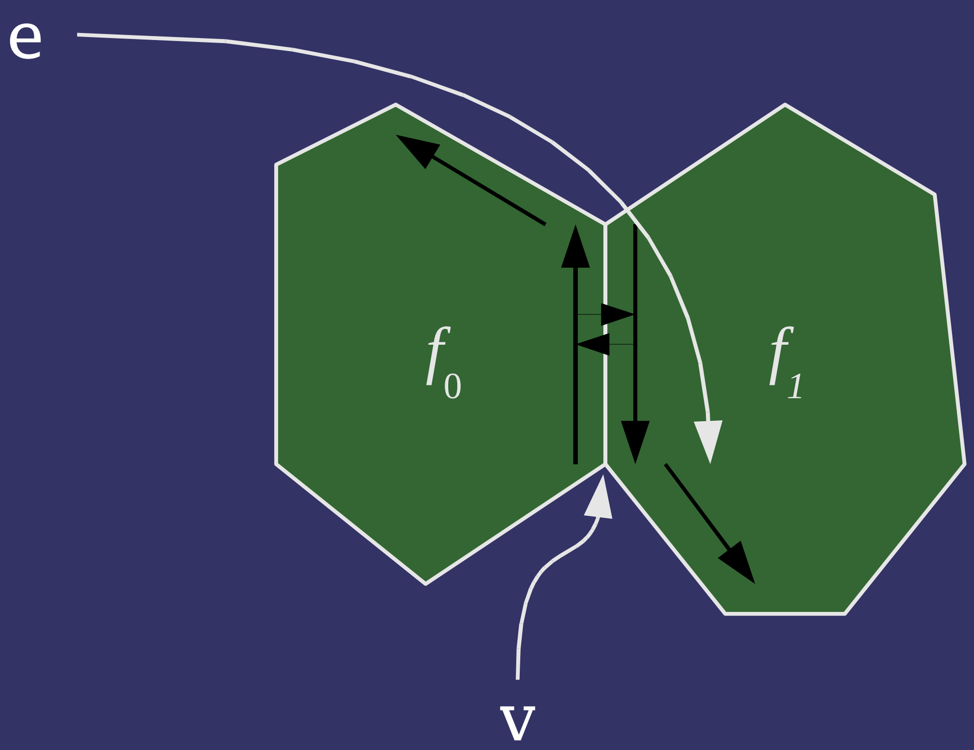
Half-Edge Mesh

- What's the problem?



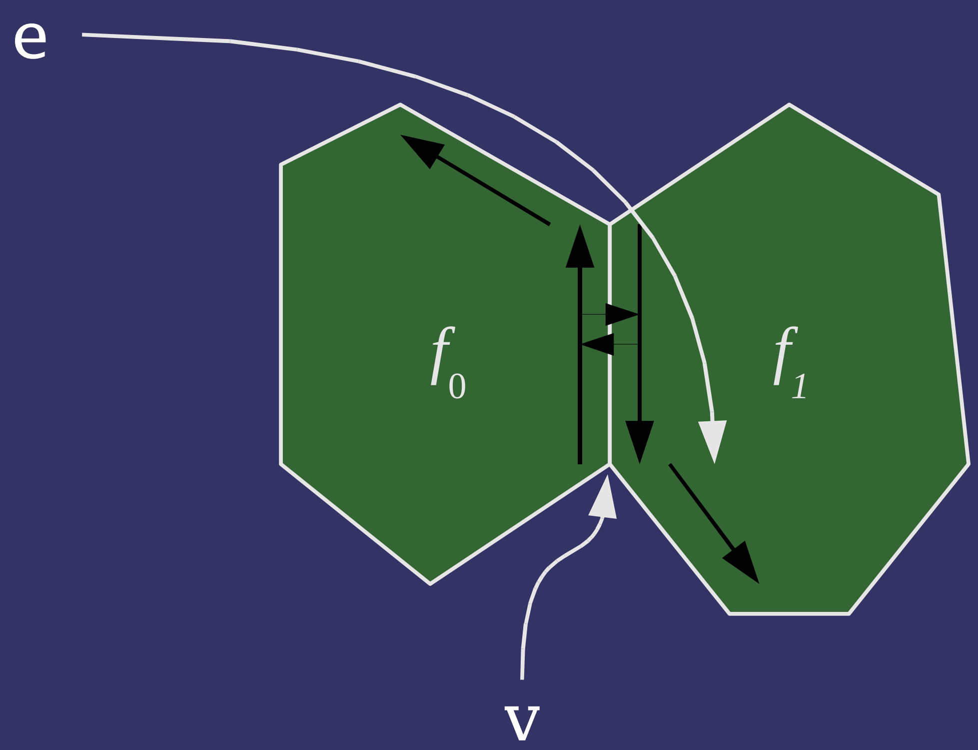
Half-Edge Mesh

- What's the problem?
  - The new e doesn't really have a sibling!
  - There are no pointers to follow to get the next edge



Half-Edge Mesh

- How can we add new edges to the mesh and prevent this problem?



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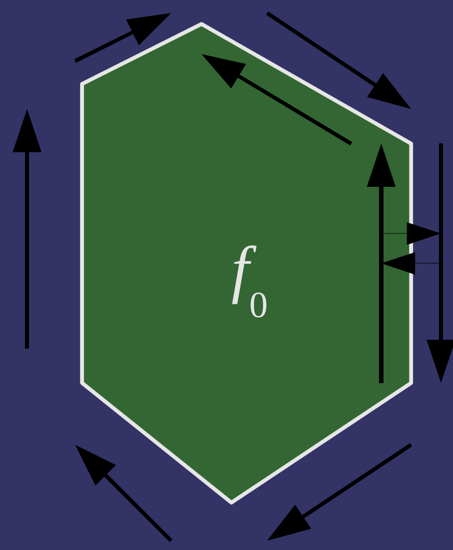
Half-Edge Mesh

- How can we add new edges to the mesh and prevent this problem?
  - As new polygons are created, the sibling edges are linked in a “fake” CCW ring
    - The polygon pointers of these HEs is `NULL`
  - Adding *new* edges is a matter of updating all the linked lists



Half-Edge Mesh

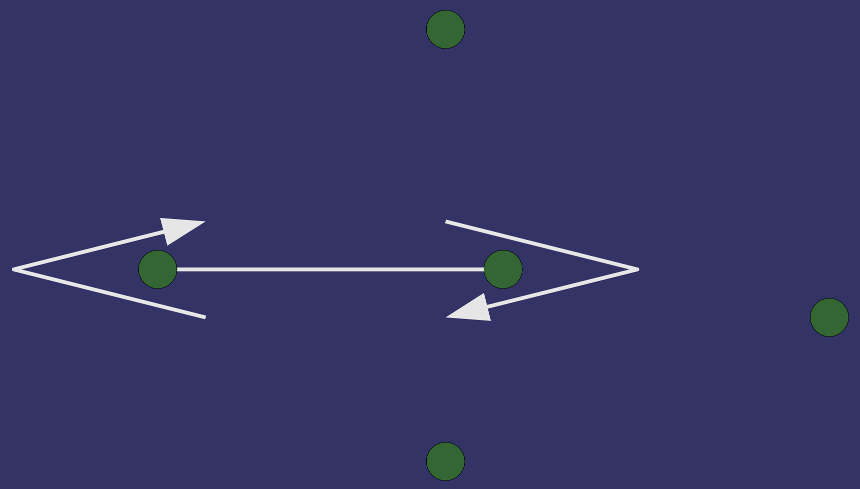
- To make the HE work, there are a few more primitives required
  - `create_edge(v0, v1)`: Create a new pair of HEs between `v0` and `v1`
  - `make_adjacent(a, b)`: Link `a` and `b` so that `a->next = b`
  - `add_polygon(edges, n)`: Create a new polygon from a list of existing edges

Half-Edge Mesh

- To create a *new* edge:
  - Allocate two HEs, link one to `v0` and the other to `v1`
  - Set both polygon pointers to `NULL`
  - Link both HEs as siblings
  - Link both HEs as each other's `next_ccw`
    - Tricky! This makes the bootstrap case work and fixes other issues in `make_adjacent`
  - Insert each edge in the “gap” in the vertex's edge list
    - Some HE where:
      - `e->sibling->v == v`
      - `e->p == NULL`
      - `e->next_ccw->v == v`

Half-Edge Mesh

- Edges can be added in arbitrary order...



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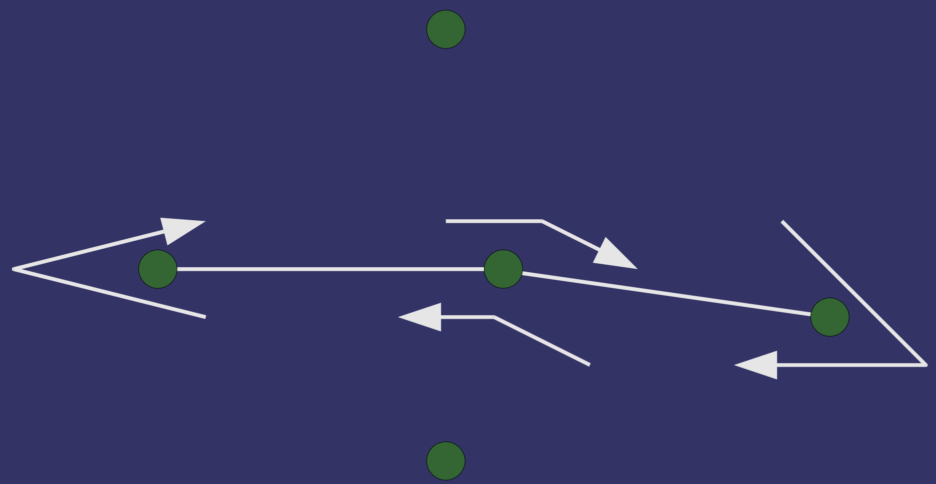

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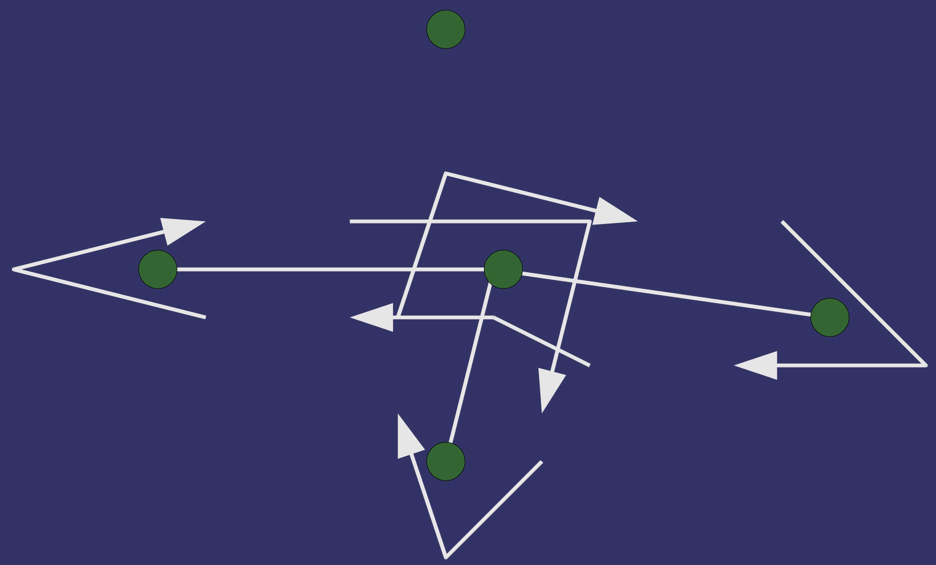

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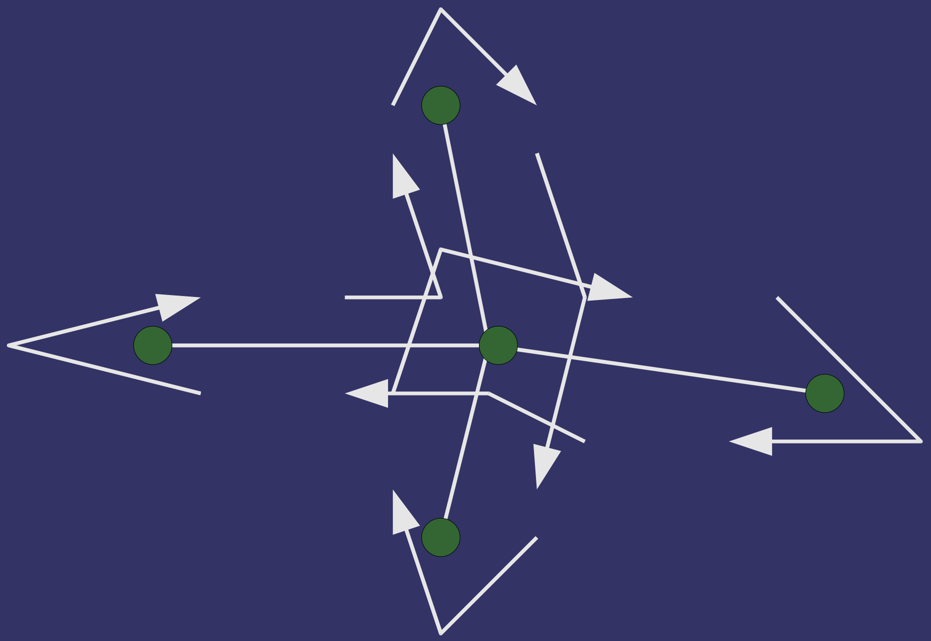

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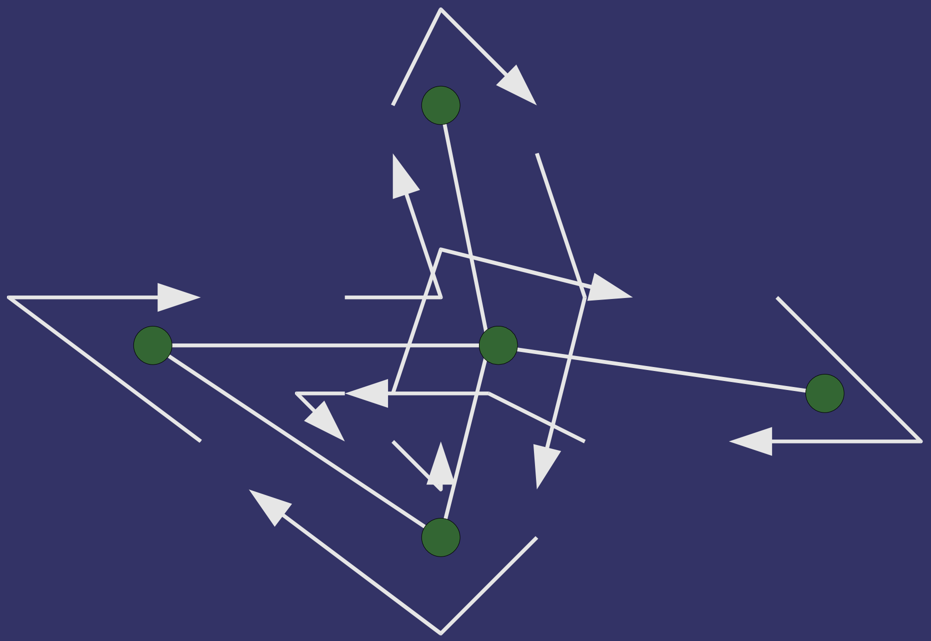

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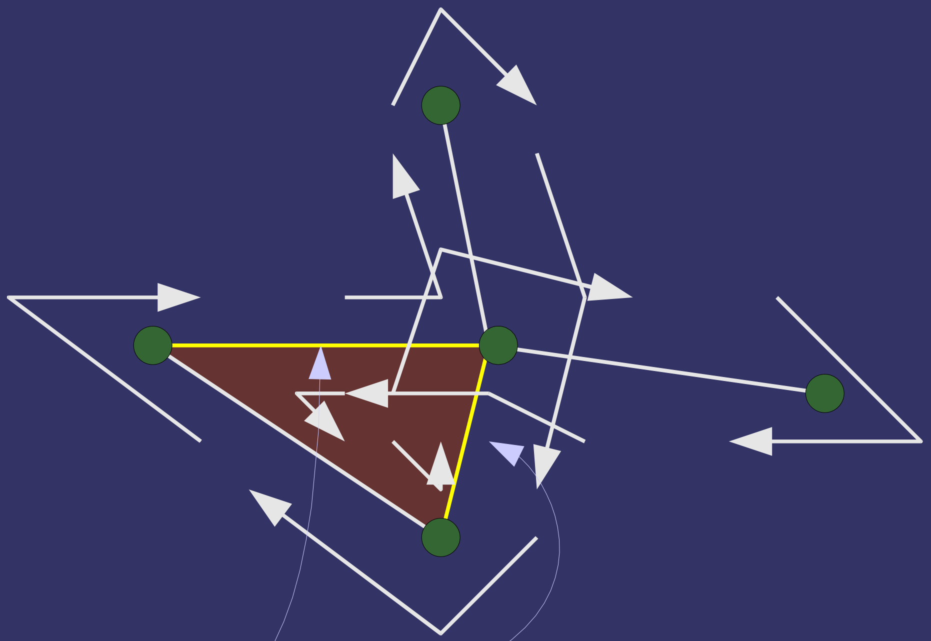
Half-Edge Mesh

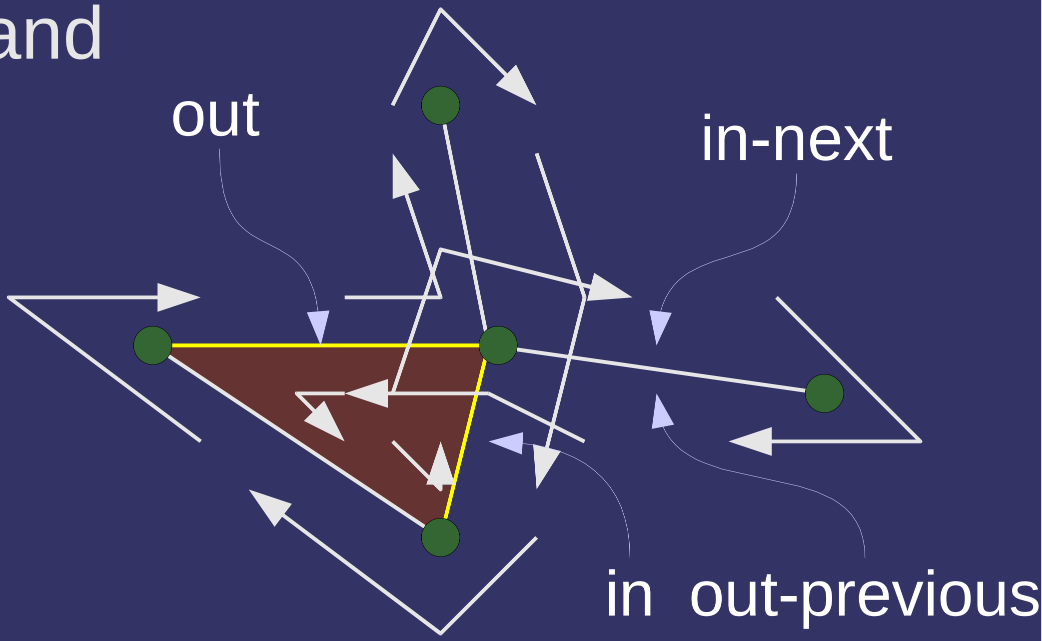
- Edges can be added in arbitrary order...
  - This causes problems when edges are formed into a polygon



These edges should be linked

Half-Edge Mesh

- Relink the edges to create the correct relationships
  - Cut the links between *in* and *in-next*, and between *out* and *out-previous*



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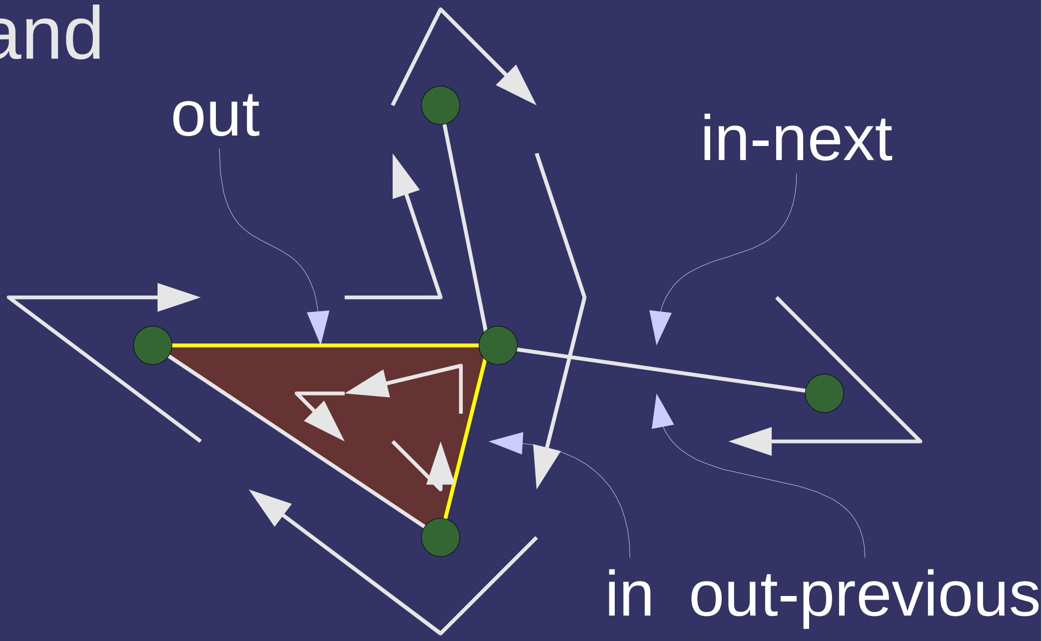

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Half-Edge Mesh

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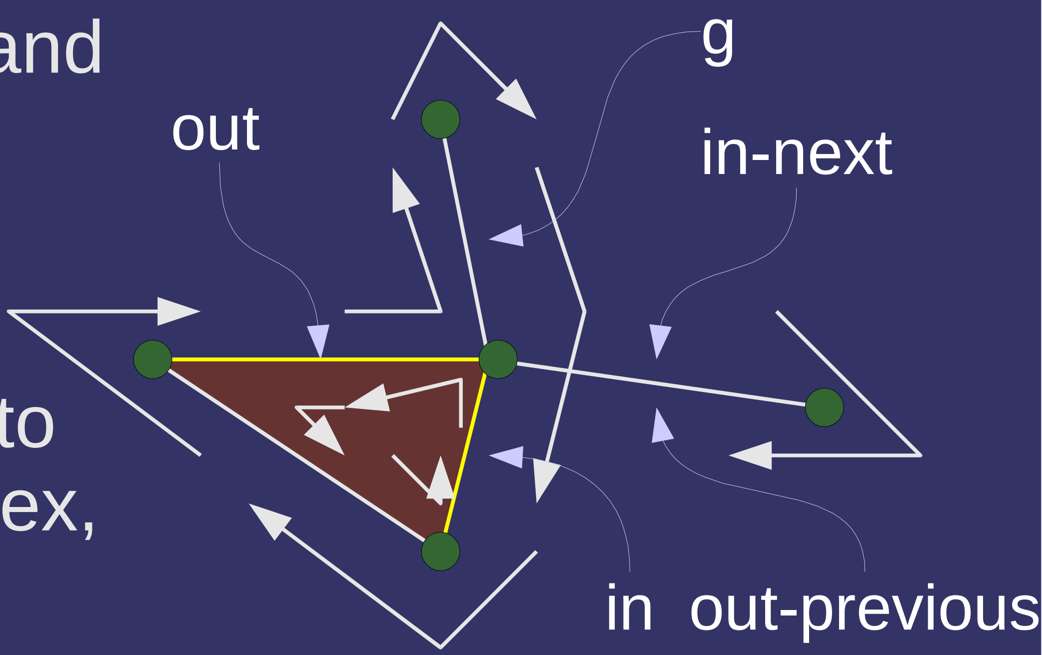
  - Link *in* and *out*
  - Find a free edge going into *in* and *out's* common vertex, call it *g*
    - This edge must be between *out-sibling* and *in*



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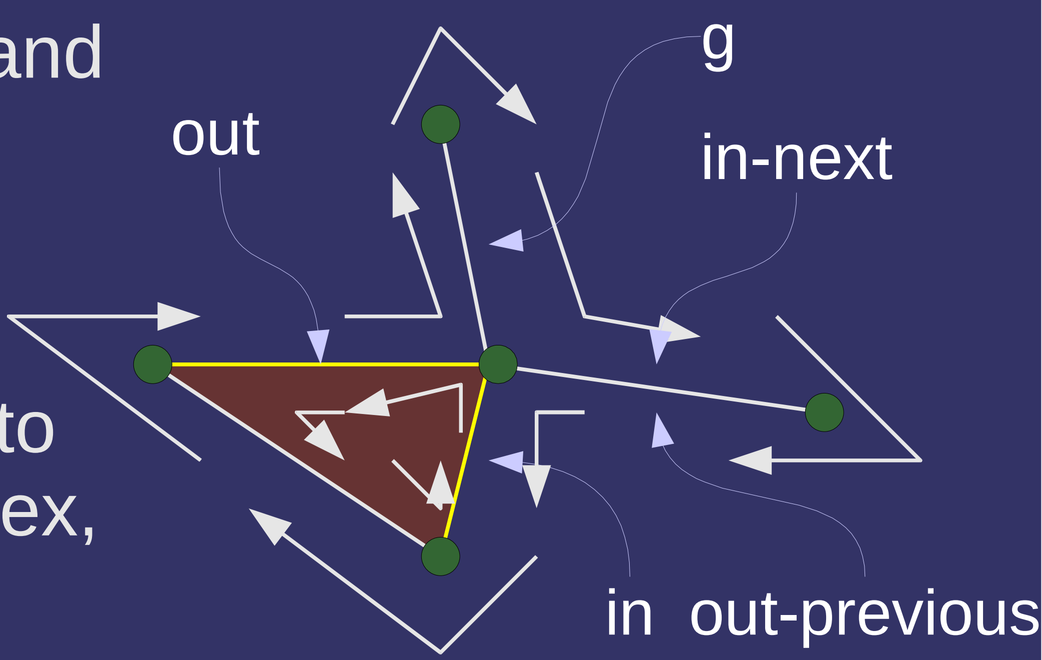

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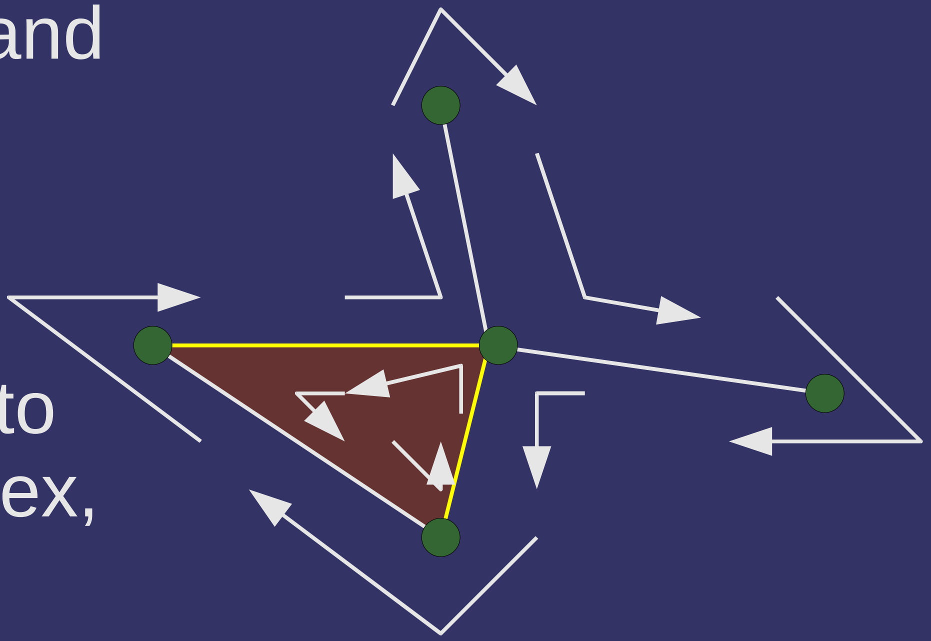

Half-Edge Mesh

- With these primitives, adding a new polygon is easy
  - For all edges, verify that the end point of one edge and the start point of the next edge is the same
  - For all edges, verify that the edge is not already associated with a polygon
  - For all edges, connect the edge to the next edge in the list
  - Allocate a new polygon object and connect all of the edges to it

References

Matt Pharr and Ken Schoemake, ed. *comp.graphics.algorithims FAQ.* Accessed 13 May 2008; available from http://cgafaq.info/wiki/Geometric_data_structures; Internet.

Shadow Volume Geometry

- Once we have a model stored half-edge or winged-edge data structure, how do we generate the shadow volume geometry?

Shadow Volume Geometry

- Once we have a model stored half-edge or winged-edge data structure, how do we generate the shadow volume geometry?
  - For each edge in the mesh:
    - If the either of the edge's polygon pointers is `NULL`, skip the edge
    - Calculate the normal of each polygon sharing the edge, call these n_0 and n_1
    - If n_0 and n_1 are equal, skip the edge
      - This happens if the surfaces are co-planar, and can *never* be on the silhouette
    - Emit a quad of (v_0, n_0), (v_1, n_0), (v_1, n_1), (v_0, n_1)

Fixing Object Geometry

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- What can we do with this?

Fixing Object Geometry

- What about edges with `NULL` polygon pointers?
  - These represent *holes* in the model
    - The Stanford bunny model has several holes in the bottom
  - For each hole, the hole-edges form a ring
- What can we do with this?
  - Walk the hole-edge ring and insert *new* edges between each pair of hole-edges
  - Each new edge will forms a triangle that fills part of the hole
  - Do this step *before* generating shadow volume geometry

Next week...

- Advanced shadow volume techniques:
  - Fixing z-pass and z-fail with ZP+
  - Hardware based optimizations:
    - Depth clamping
    - Depth bounds testing

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