Ambiguous Input and Layered Manufacturing

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Winding Numbers

• What’s “in” self-intersecting polygons?
• Winding numbers
  – Defined for point P not on boundary
  – Boundary elastic rubber band
  – If it contracts, number of CCW wraps around P
  – CW wraps count negative
Winding Numbers

1

-1

0

1

2
Winding Numbers
Winding Numbers

CONTOURS AND WINDING NUMBERS

1

2

3
Winding Numbers
Winding Number Rules
Winding Number Rules
Winding Number Rules
Ambiguous Input
Ambiguous Input

- Implicit union
Ambiguous Input

- Implicit union

(2D slice)
Ambiguous Input

- Implicit union

(2D slice)
Ambiguous Input

- Implicit union

(2D slice)
Ambiguous Input

- Implicit union
Ambiguous Input

- Implicit difference

(2D slice)
Ambiguous Input

• Implicit difference
Ambiguous Input

• Implicit difference
Ambiguous Input

- Implicit difference
Ambiguous Input

- Implicit difference
Ambiguous Input

- Implicit difference
Ambiguous Input

- Self-intersecting contour
Ambiguous Input

• Self-intersecting contour
Ambiguous Input

- Self-intersecting contour
Self Intersections

- May even be introduced during “clean-up”
Self Intersections

- May even be introduced during “clean-up”
  - Cow model’s tail intersected body
- Some interpretations produce non-manifold part
  - Structurally weak
- Preferred interpretation is unary union
Implicit Booleans

• Even if exchange format doesn’t include *explicit* CSG, *implicit* Booleans will arise
• Manufacturers don’t categorically reject
  – 2D Booleans are relatively easy to resolve
  – OpenGL winding number rules can compute them
Winding Number Booleans

• What winding number rule(s):
  – will treat intersecting CCW contours as implicit unions?
  – will treat self-intersecting CCW contours as unary unions?
  – will correctly calculate implicit differences?
Winding Number Booleans

- **Unions**
  - Non-zero rule
  - Positive rule

- **Self-intersections**
  - Non-zero rule
  - Positive rule

- **Differences**
  - (CW orientation for subtractands)
  - Positive rule
Winding Number Booleans

• What’s with the “Absolute value >= 2” rule?
  – Intersection of 2 CCW contours

• Combined w/ positive rule, allows all Booleans to be displayed w/out evaluating
Acknowledgements

- OpenGL Programming Guide