DATA SCIENCE IN MANUFACTURING
WEEK 10

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LECTURE: WEEK 10

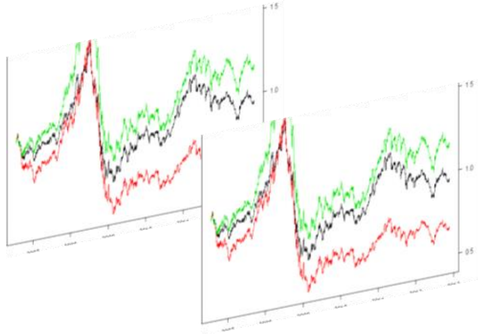
Data Representation / EBoM / MBoM / Geometry / Time Series

BY THE END OF THIS LECTURE YOU SHOULD:

- To introduce and understand the concept of Engineering BoM
- To introduce and understand the concept of Manufacturing BoM
- Geometry
- Time series

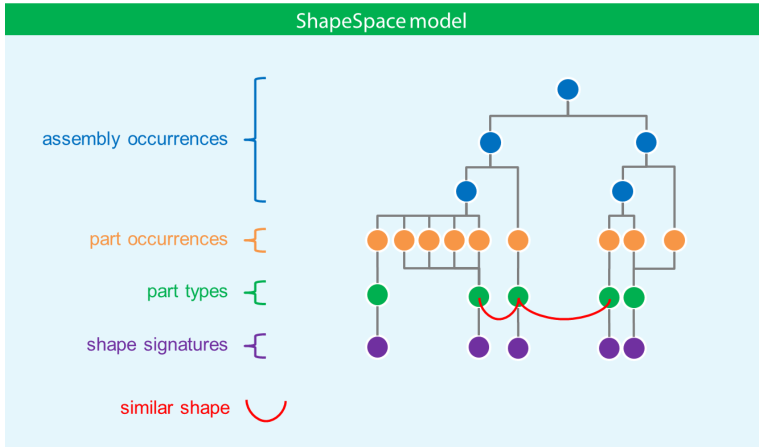
Traditional Analytics

Tabular Data

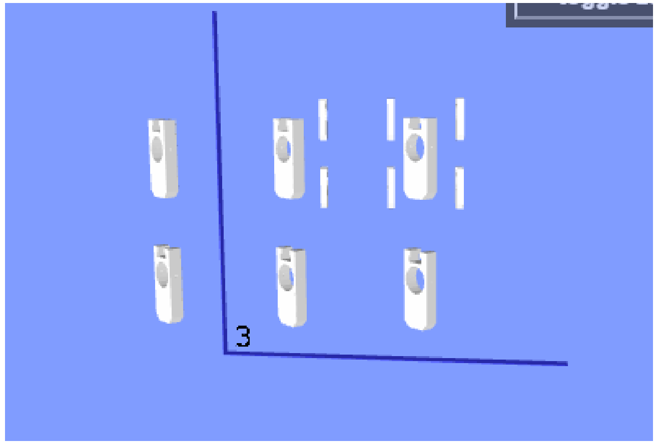


Time Series Data

ShapeSpace Analytics: Targeted at manufacturing data



Product Structure / BoM



Component Geometry

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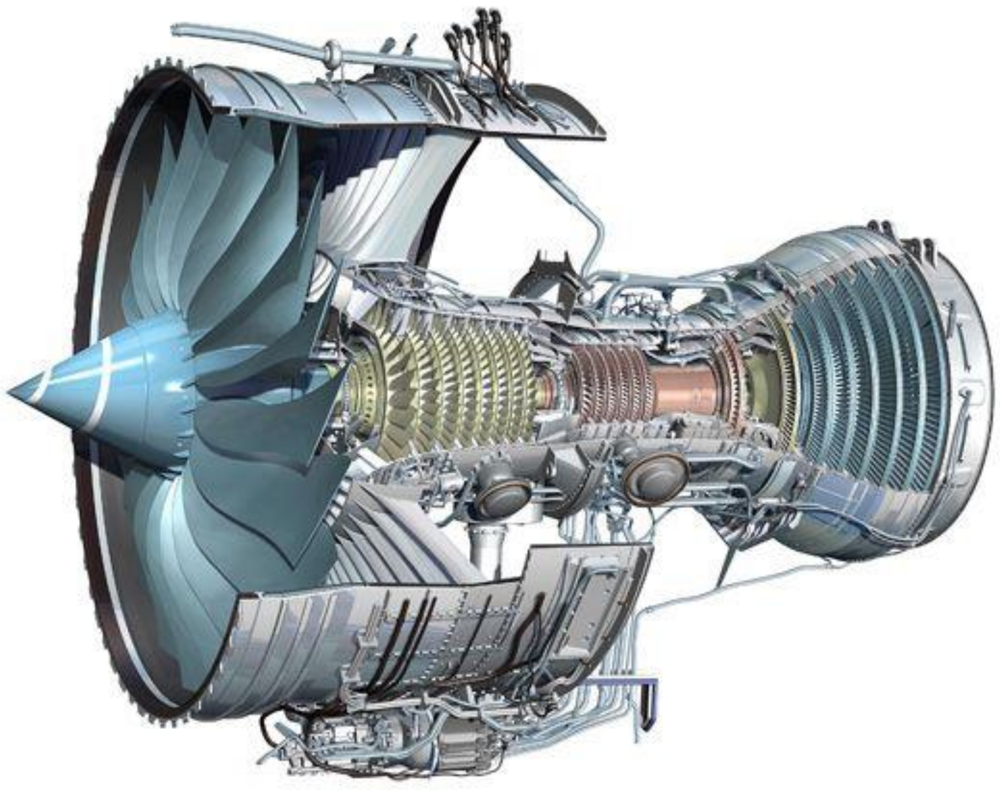
EBOM / MBOM

WHY?

In a previous lecture we discussed an inventory database to manage products for an electronics retailer.

Each product could be thought of as a single ‘Stock Keeping Unit’ (SKU).

However, if we are concerned with manufacturing complex products we need to consider the parts and assemblies in the product.



PRODUCT STRUCTURE

It is usually useful to consider a product as a hierarchical structure of components:

A *component* is an individual part of a product.

An *assembly* is a collection of components and/or assemblies assembled together.

A *sub-assembly* is an assembly that forms part of a larger assembly.

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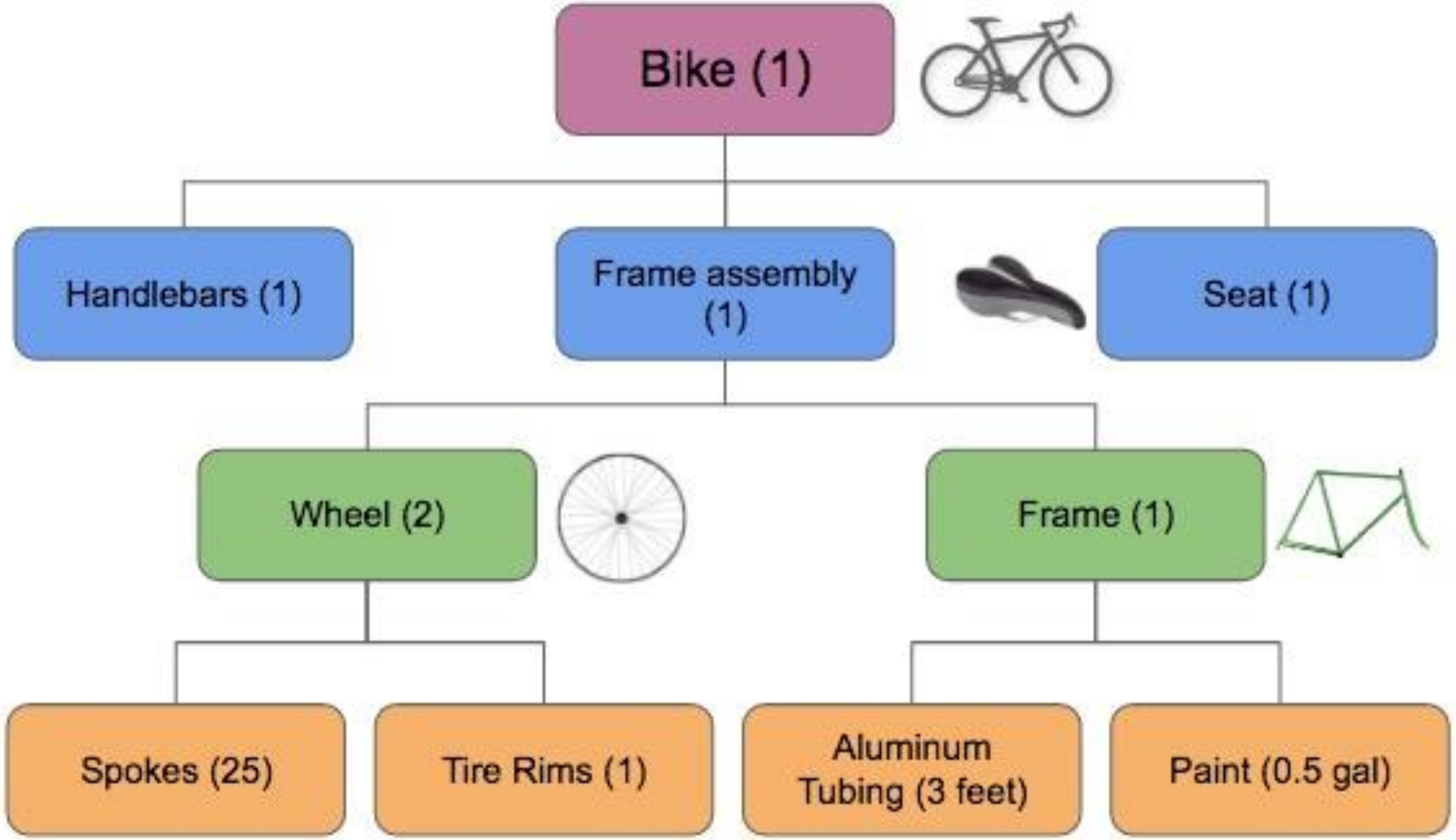
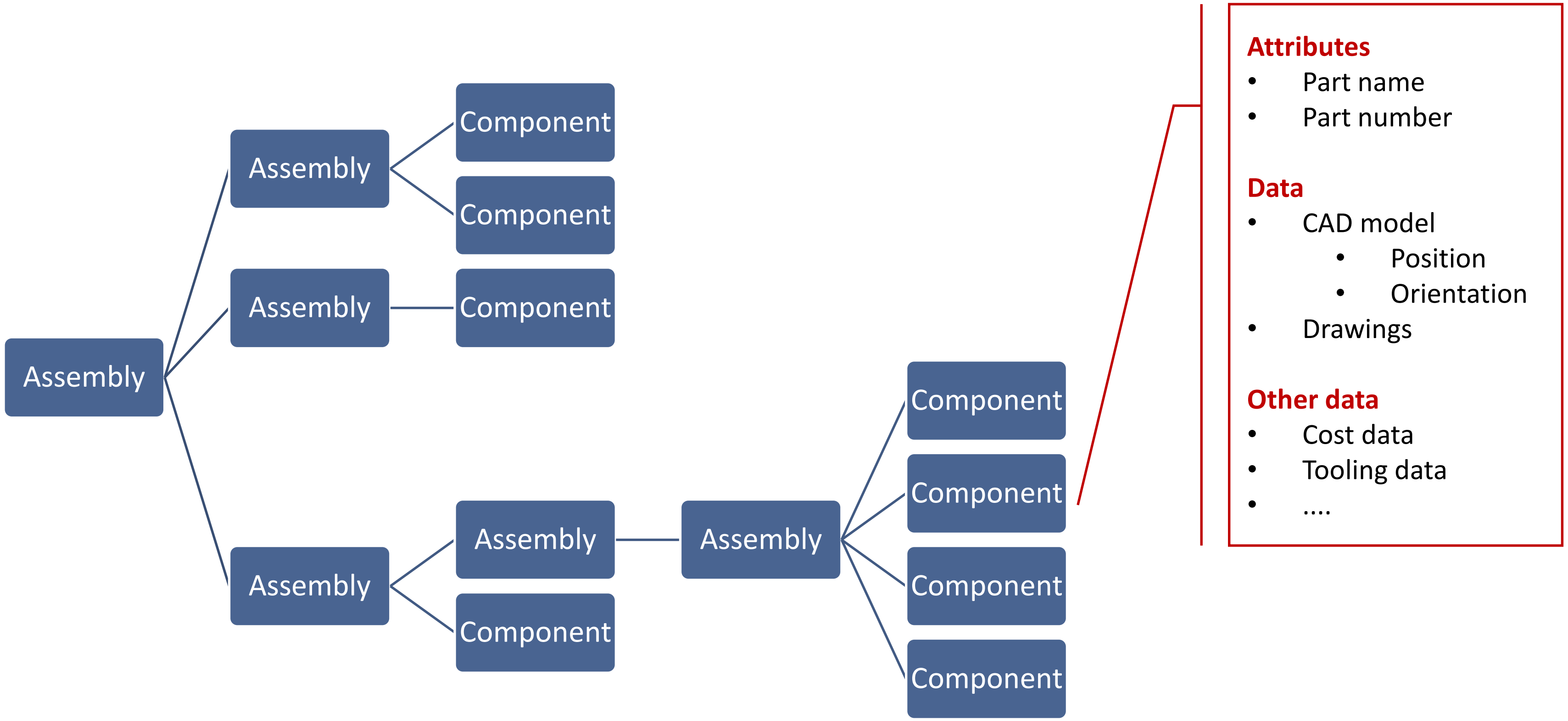
PRODUCT STRUCTURE



PRODUCT STRUCTURE



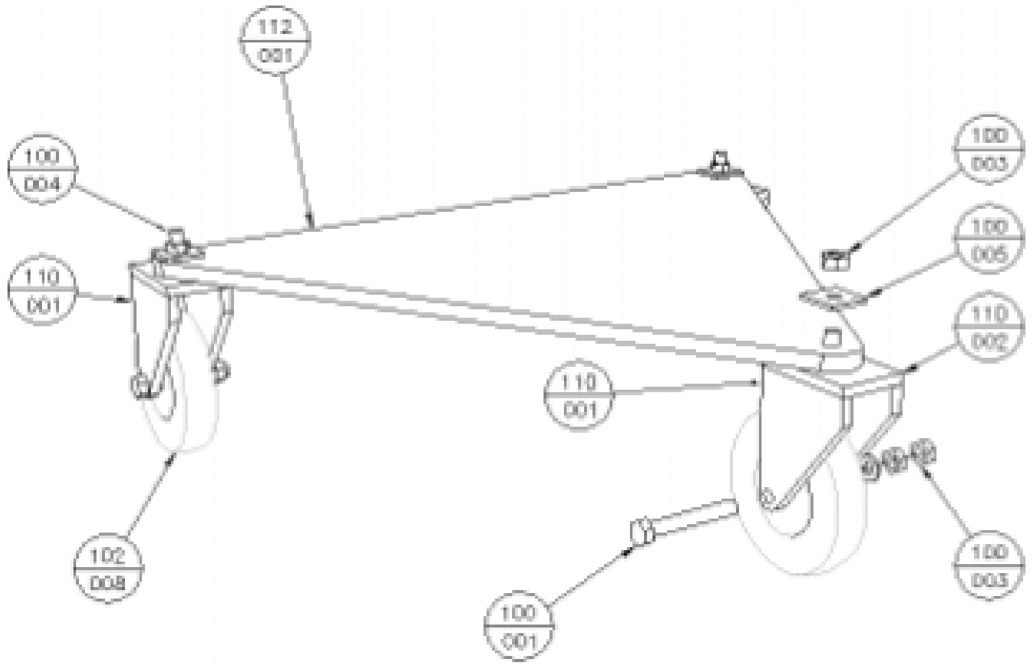
BILL OF MATERIALS

From Wikipedia:

A bill of materials (sometimes bill of material, BOM or associated list) is a list of the raw materials, sub-assemblies, intermediate assemblies, sub-components, parts and the quantities of each needed to manufacture an end product.

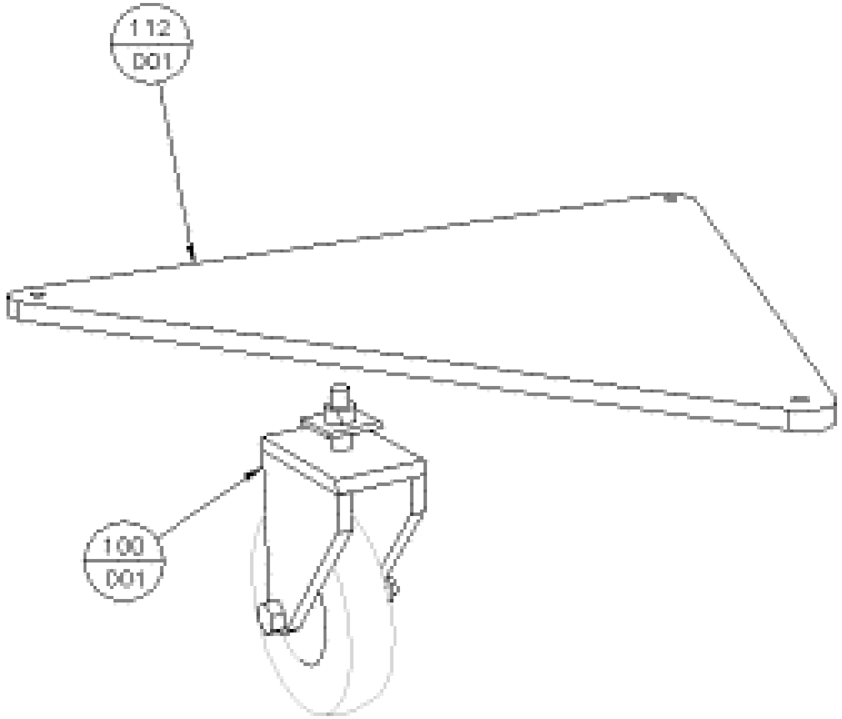
BILL OF MATERIALS

- Example from billofmaterials.net:



BILL OF MATERIALS

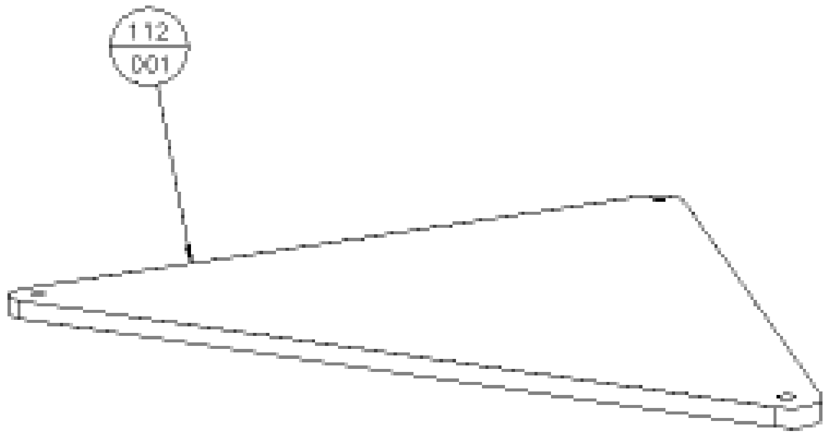
Top level



Level	Part No	Description	Group	Unit	QTY
1	120-001	Trolley, 3 wheeled	Assy	EA	1.0000
2	112-001	Plywood Platform	Part	EA	1.0000
2	110-001	Wheel Housing	Assy	EA	3.0000

BILL OF MATERIALS

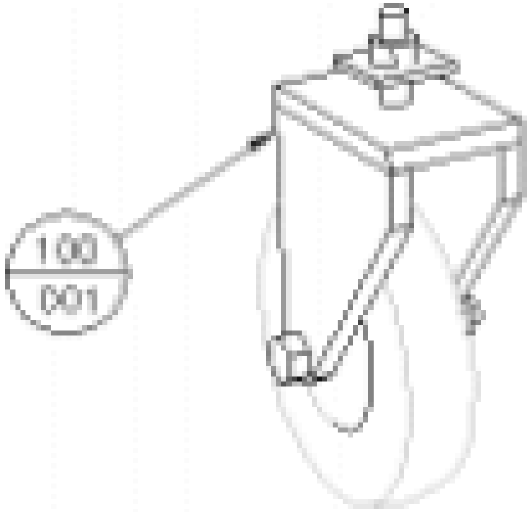
The platform



Level	Part No	Description	Group	Unit	QTY
1	112-001	Plywood Platform	Part	EA	1.0000
2	106-001	Plywood,12mm,2400x1200	RM	SH	0.1250
2	111-006	Varnish, Semi Gloss	PR	L	0.0500

BILL OF MATERIALS

The wheel assembly



Level	Part No	Description	Group	Unit	QTY
1	110-001	Wheel Housing	Assy	EA	3.0000
2	110-003	Side Piece	Part	EA	2.0000
2	110-002	Top Piece	Part	EA	1.0000
2	102-108	Wheel, with tyre, 100mm	Part	EA	1.0000
2	100-001	MS Bolt, M10x70, Galv	Fast	EA	1.0000
2	100-002	M10, washer, Galv	Fast	EA	2.0000
2	100-003	M10, Nut, Galv	Fast	EA	3.0000
2	100-004	MS Bolt, M10x30, Galv	Fast	EA	1.0000
2	100-005	M10 Square Nut	Fast	EA	1.0000

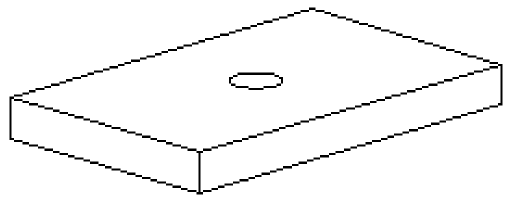
BILL OF MATERIALS

The side pieces

Level	Part No	Description	Group	Unit	QTY
1	110-003	Side Piece	Part	EA	2.0000
2	105-001	MS Flat 80x8	RM	M	0.1000
2	111-001	Galvanising	PR	KG	0.0010

BILL OF MATERIALS

The top piece

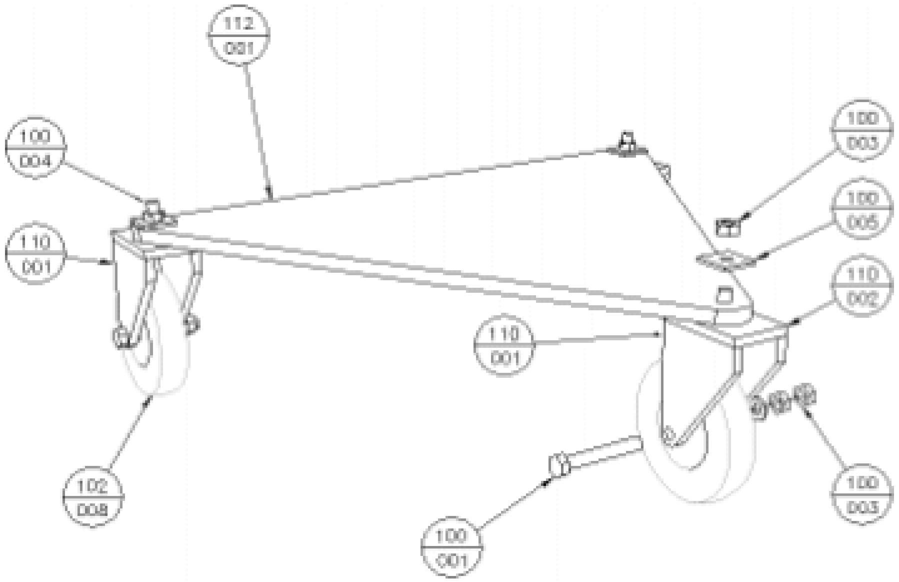


Level	Part No	Description	Group	Unit	QTY
1	110-002	Top Piece	Part	EA	1.0000
2	105-001	MS Flat 80x8	RM	M	0.0500
2	111-001	Galvanising	PR	KG	0.0010

BILL OF MATERIALS

The product

Level	Part No	Description	Group	Unit	QTY	Waste %	Ext QTY
1	120-001	Trolley, 3 wheeled	Assy	EA	1.0000	0.0000	1.0000
2	112-001	Plywood Platform	Part	EA	1.0000	0.0000	1.0000
3	106-001	Plywood,12mm,2400x1200	RM	SH	0.1250	0.0000	0.1250
3	111-006	Varnish, Semi Gloss	PR	L	0.0500	0.1000	0.0501
3	130-001	Labor	LB	HR	0.6500	0.0000	0.6500
2	110-001	Wheel Housing	Assy	EA	3.0000	0.0000	3.0000
3	110-003	Side Piece	Part	EA	2.0000	0.0000	2.0000
4	105-001	MS Flat 80x8	RM	M	0.1000	5.0000	0.1050
4	111-001	Galvanising	PR	KG	0.0010	0.0000	0.0010
4	130-000	Labor	LB	HR	0.1000	0.0000	0.1000
3	110-002	Top Piece	Part	EA	1.0000	0.0000	1.0000
4	105-001	MS Flat 80x8	RM	M	0.0500	5.0000	0.0525
4	111-001	Galvanising	PR	KG	0.0010	0.0000	0.0010
4	130-000	Labor	LB	HR	0.5000	0.0000	0.5000
3	102-108	Wheel, with tyre, 100mm	Part	EA	1.0000	0.0000	1.0000
3	100-001	MS Bolt, M10x70, Galv	Fast	EA	1.0000	0.0000	1.0000
3	100-002	M10, washer, Galv	Fast	EA	2.0000	0.0000	2.0000
3	100-003	M10, Nut, Galv	Fast	EA	3.0000	0.0000	3.0000
3	100-004	MS Bolt, M10x30, Galv	Fast	EA	1.0000	0.0000	1.0000
3	100-005	M10 Square Nut	Fast	EA	1.0000	0.0000	1.0000



BILL OF MATERIALS

The product

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4	130-000	Labor	LB	HR	0.1000	0.0000	0.1000
3	110-002	Top Piece	Part	EA	1.0000	0.0000	1.0000
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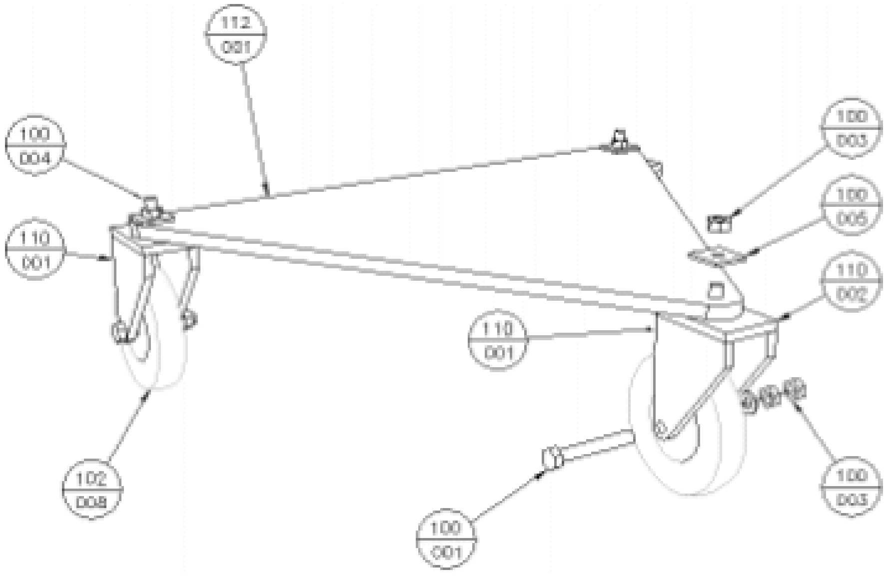
3	102-108	Wheel, with tyre, 100mm	Part	EA	1.0000	0.0000	1.0000
3	100-001	MS Bolt, M10x70, Galv	Fast	EA	1.0000	0.0000	1.0000
3	100-002	M10, washer, Galv	Fast	EA	2.0000	0.0000	2.0000
3	100-003	M10, Nut, Galv	Fast	EA	3.0000	0.0000	3.0000
3	100-004	MS Bolt, M10x30, Galv	Fast	EA	1.0000	0.0000	1.0000
3	100-005	M10 Square Nut	Fast	EA	1.0000	0.0000	1.0000



Should labour be
in BoM?

BILL OF MATERIALS

- Exercise:

- Build a BoM for a UK electrical plug

BILL OF MATERIALS

Level	Part Number	Description	Unit	Qty
1	P_1	Plug	Ea	1
2	C_1	Lid	Ea	1
2	C_2	Screw	Ea	1
2	A_1	Bottom Assembly	Ea	1
3	C_2	Base	Ea	1
3	A_2	Earth Pin Assembly	Ea	1
4	C_3	Small Screw	Ea	1
4	C_4	Earth Pin	Ea	1
3	A_3	Neutral Pin Assembly	Ea	1
4	C_3	Small Screw	Ea	1
4	C_5	Neutral Pin	Ea	1
3	A_4	Live Pin Assembly	Ea	1
4	C_6	Fuse	Ea	1
4	A_5	Live Pin Holder Assembly	Ea	1
5	C_7	Fuse Holder	Ea	1
5	C_3	Small Screw	Ea	1
4	C_8	Live Pin	Ea	1
2	C_9	Cable Holder	Ea	1
2	C_10	Cable Holder Screw	Ea	2

BILL OF MATERIALS

Some questions:

Is this the structure as designed?

Is this enough information to manufacture the plug?

Is this enough information to sell the plug?

BILL OF MATERIALS

Some questions:

Is this the structure as designed?

The engineering bill of materials (EBOM) is a special type of bill of material which defines the product as designed. It contains the list of items, parts, components, sub-assemblies and assemblies in the product designed by engineering.

BILL OF MATERIALS

Some questions:

Is this enough information to manufacture the plug?

Consider the Live Pin: to make this part we would also need to have parts for the holder, rivet, lower metal pin and upper plastic pin.

The manufacturing bill of materials (MBOM) a bill of material which defines the parts, assemblies, adhesives, paints, etc. and perhaps software/firmware to build a complete product.

BILL OF MATERIALS

Some questions:

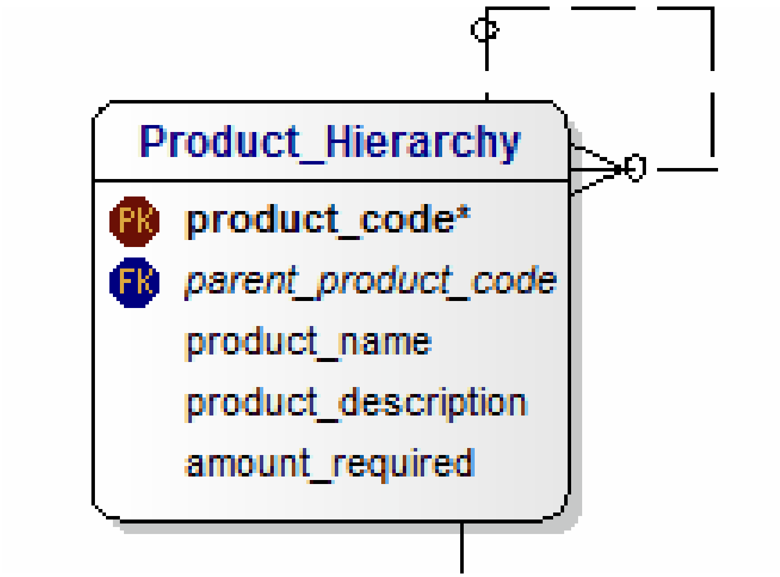
Is this enough information to sell the plug?

Consider the sticky labels and card instructions. Is there packaging or perhaps regulatory concerns such as instructions and labelling. Should these be included in the BoM.

These could be included in the MBOM, but there may also be a sales specific Sales BoM.

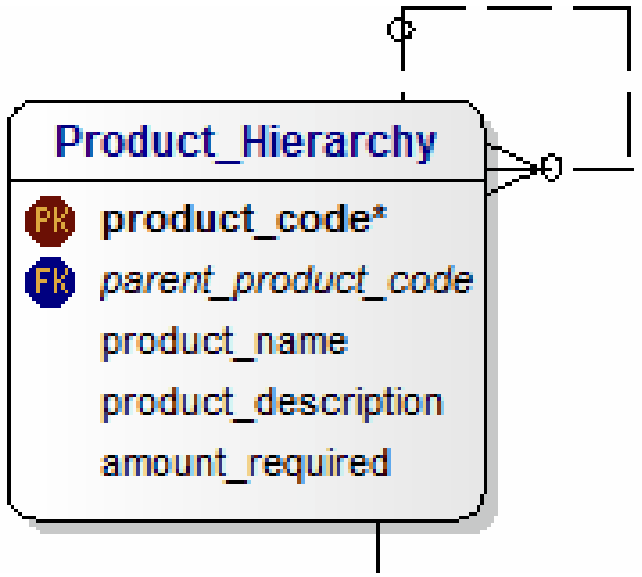
REPRESENTING A BOM

Relational Database



REPRESENTING A BOM

Relational Database

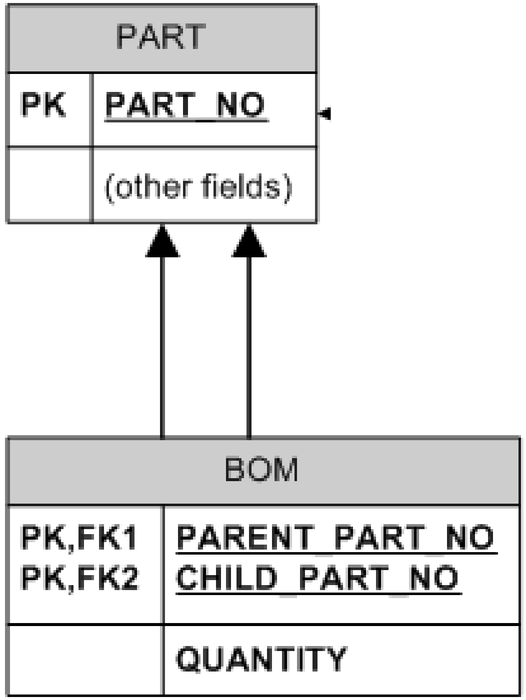


Can represent items with multiple children.

Assumes there is only one parent for each part.

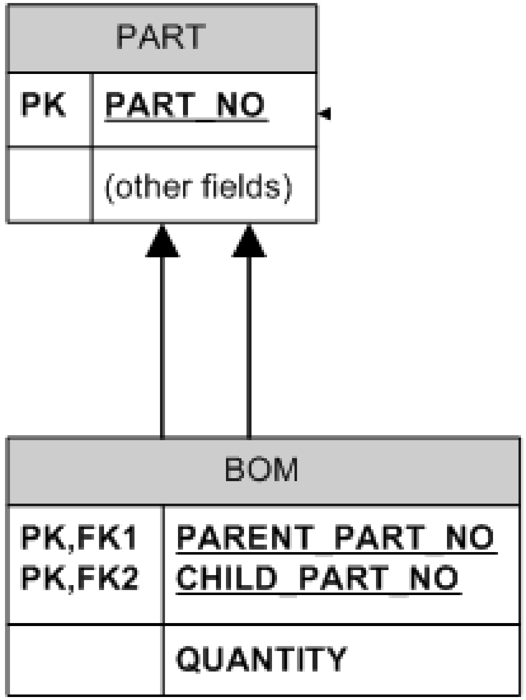
REPRESENTING A BOM

Relational Database



REPRESENTING A BOM

Relational Database

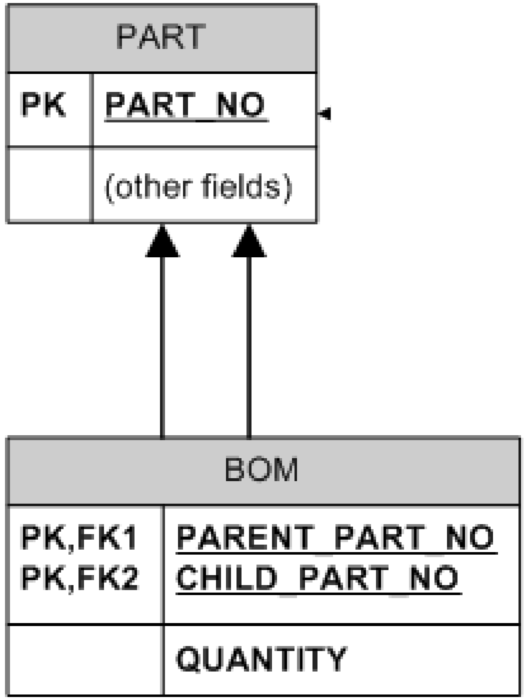


Can represent items with multiple children and multiple parents for each item.

However, let's think about an SQL query to retrieve the BoM for a top-level part.

REPRESENTING A BOM

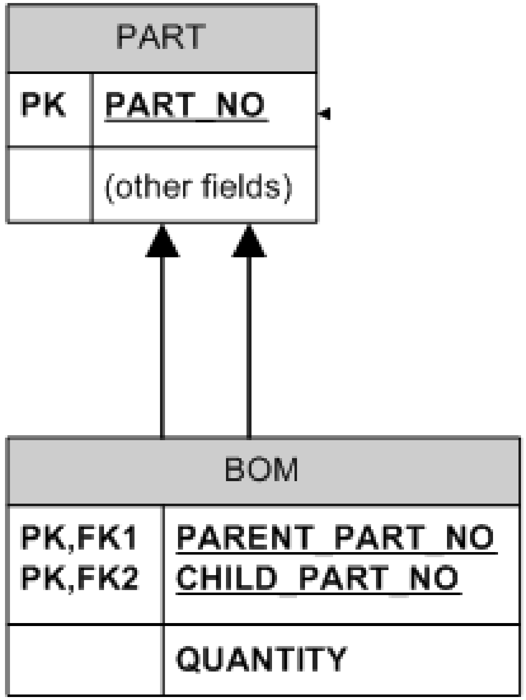
Relational Database




```
SELECT *
  FROM PART

LEFT OUTER JOIN BOM
  ON PART.PART_NO =
BOM.PARENT_PART_NO

LEFT OUTER JOIN PART
  ON BOM.CHILD_PART_NO = PART_NO

WHERE PART.PART_NO = 'ABC123'
```

REPRESENTING A BOM

Relational Database




```
SELECT *
  FROM PART

LEFT OUTER JOIN BOM
  ON PART.PART_NO =
BOM.PARENT_PART_NO

LEFT OUTER JOIN PART
  ON BOM.PARENT_CHILD_NO =
PART_NO

WHERE PART.PART_NO = ‘ABC123’
```

However, this only takes us down one level of the BoM. We could write a *recursive* SQL query, but multiple JOINS can get slow…

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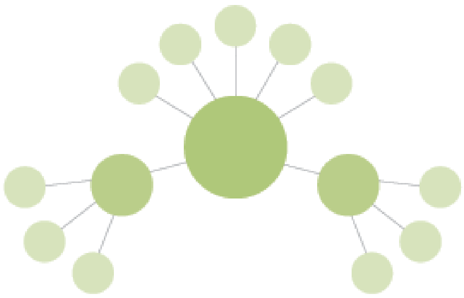
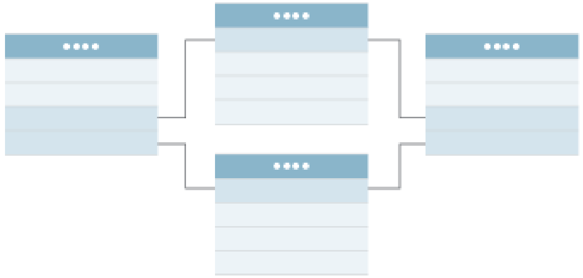
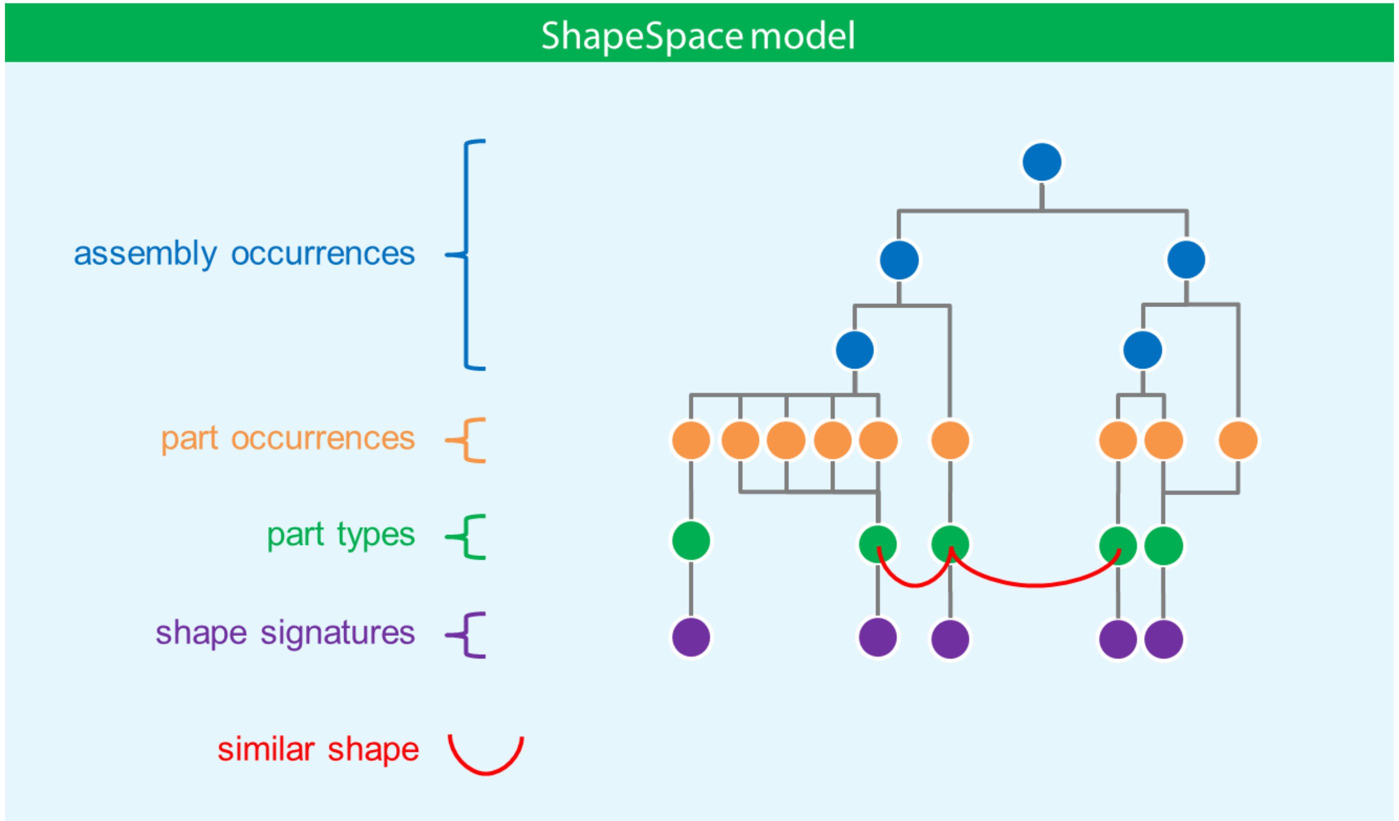
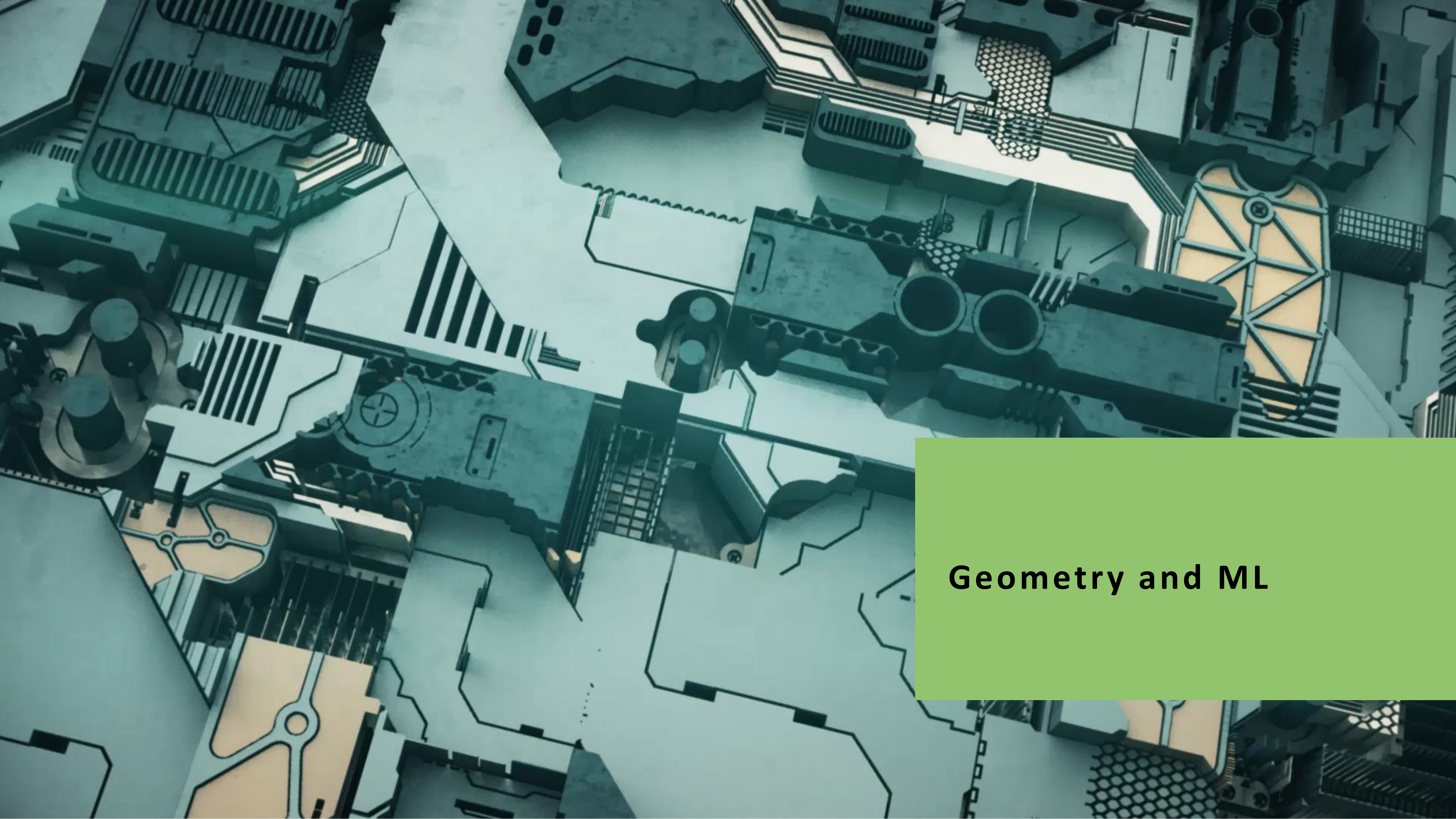
GRAPH DATABASES

	Graph database	Relational database
FORMAT	Nodes and edges	Tables with rows and columns
RELATIONSHIPS	Considered data, represented by edges between nodes	Related across tables, established using foreign keys between tables
COMPLEX QUERIES	Run quickly and do not require joins	Require complex joins between tables
TOP USE CASES	Relationship-heavy use cases, including fraud detection and recommendation engines	Transaction-focused use cases, including online transactions and accounting
EXAMPLE		

GRAPH DB FOR BOMS





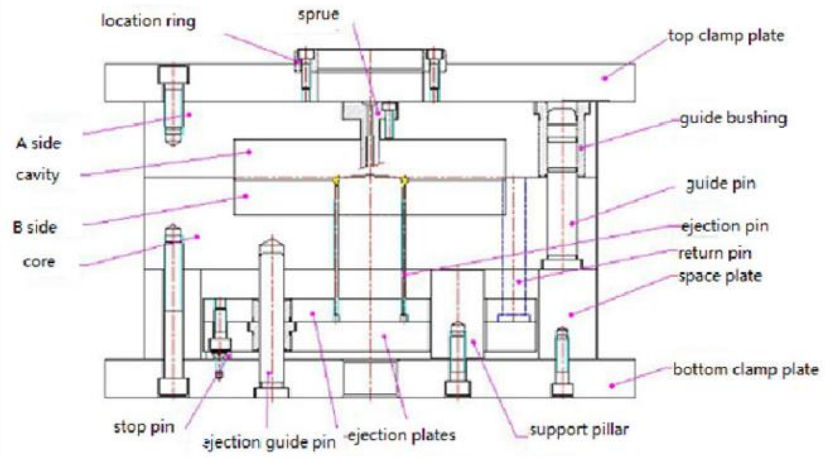
Geometry and ML

WHAT IS A MOULD OR TOOL

Workshop

Two plate mold

Two plate mold is the easiest injection mold structure and has many advantages. It's consist with A side and B side 2 main parts, when it is load in ejection machine to do molding, A side is fixed and held still, B side is movable. See below figure to get the details of the 2 plate mold.



Some of the term explanation:

Location ring: location the filling hole between injection nozzle and sprue, usually made of S55C

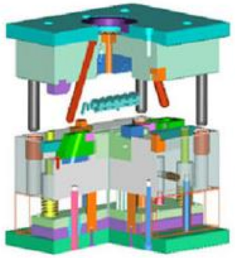
Return pin: ensure the ejector pin pull back before the mold close, it protects the injection mold from damage, it's usually made of SKD61.

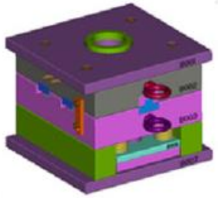
Guide pin/ guide bushing: GP and GB are designed for precision guiding so the GP and GB have to be precise themselves.

Ejector guide pin: during ejection, EGP works as guiding to ensure the ejection is correct.

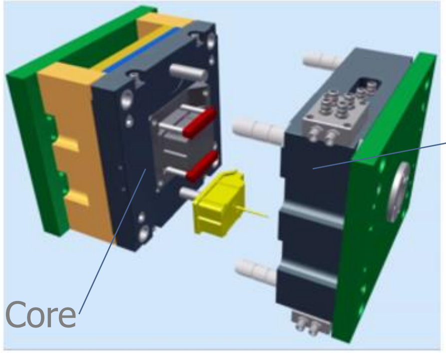
Support pillar: support the B side plate to avoid deformation under high injection pressure.

Spure: allow the melt flow into the cavity.





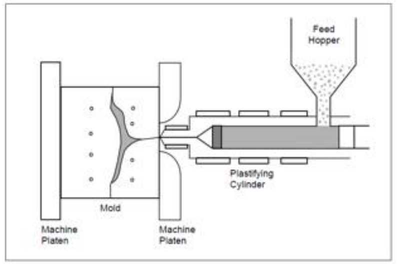
Mould Tool

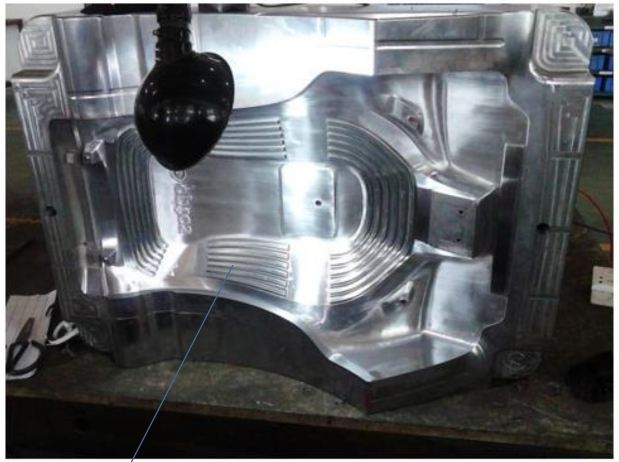


Core

Cavity

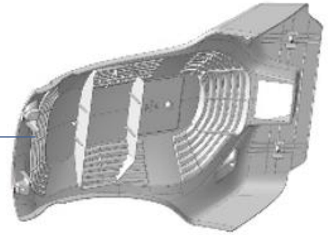
Figure 2.02 Schematic cross section of the plastifying cylinder and mold



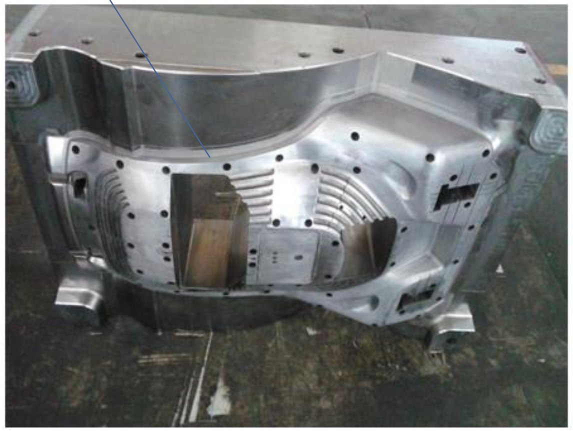


Cavity

Part



Core



COSTING LOGIC

Workshop

Size / weight

small 1,1	medium 2,3
3,5 large	5,10 Very large

How many Parts

1 part (simple) 1,1	2-5 parts 3,5
4,8 5-20 parts	5,10 20+parts (complex)

Part Complexity

Simple 1,1	Medium 1,3
1,8 High	1,10 Very high

Material

Low cost 1,1	Medium 4,1
8,1 High	10,1 Very high

Secondary Ops

None – moulded as is 1,1	Simple – add inserts 4,1
8,1 Plating or coatings required	10,1 High complexity, fasteners, coating & sub assembly ops req.

Batch Volume

Low (500-1000) 1,1	Medium 1,000-10,000 2,1
3,3 High 10k-100k	4,10 Very high 100k+.

Greatly Influences part cost 1-10 (10 being the more expensive)

Greatly Influences tool cost 1-10 (10 being the more expensive)

Note – these are very general assumptions & do not work for all parts – need to check these with McLaren Plastic)

COSTING LOGIC

Workshop

Size / weight

small 1,1	medium 2,3
large 3,5	Very large 5,10

How many Parts

1 part (simple) 1,1	2-5 parts 3,5
5-20 parts 4,8	20+parts (complex) 5,10

Part Complexity

Simple 1,1	Medium 1,3
High 1,8	Very high 1,10

Initial work by UoE was concentrating on these areas

Material

Low cost 1,1	Medium 4,1
High 8,1	Very high 10,1

Secondary Ops

None – moulded as is 1,1	Simple – add inserts 4,1
Plating or coatings required 8,1	High complexity, fasteners, coating & sub assembly ops req. 10,1

Batch Volume

Low (500-1000) 1,1	Medium 1,000-10,000 2,1
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Note – these are very general assumptions & do not work for all parts – need to check these with McLaren Plastic)

Sliders

Sliders are a way of overcoming undercuts in the design by having an additional piece of steel in the tool with its own line of draw.

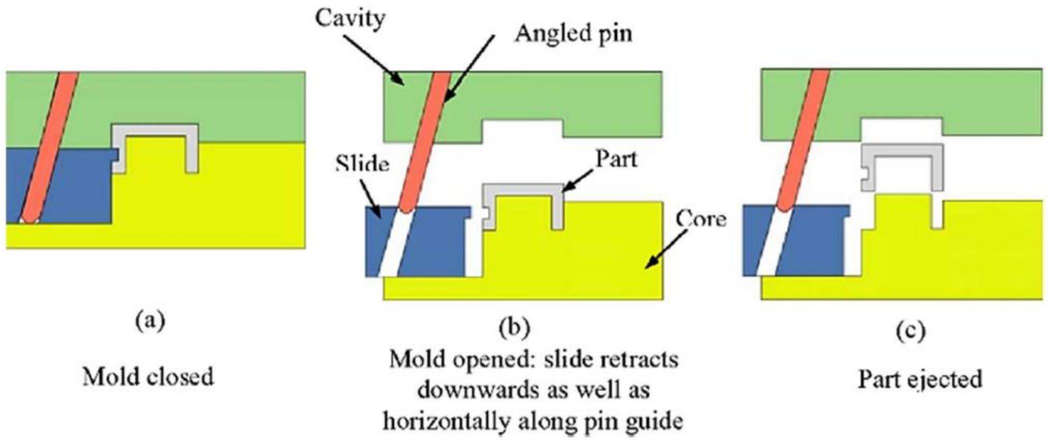
Sliders generally form features on the outside of the part as they can be driven mechanically.

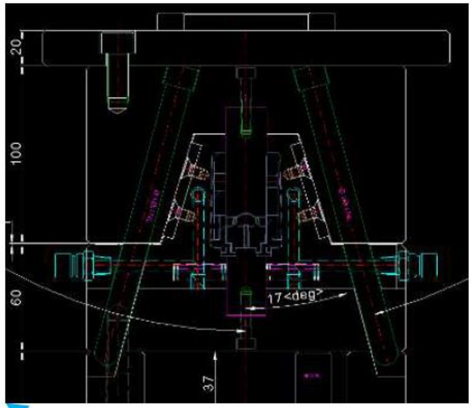
As the cavity tool moves away a pin or angled block extracts the slider from the part. With the slider moved out of position the part is free to be ejected.

The slider will have its own split line around the area which it forms. Within this area all the features should be draft in the direction the slider moves using the same principles as the cavity and core.

Note: Draft tool wont show split line of slider

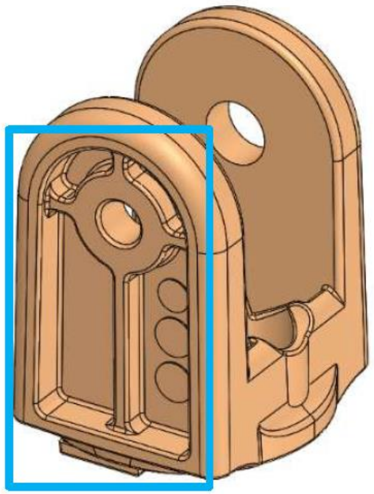
Edi Uni - Sliders are on the outside of parts



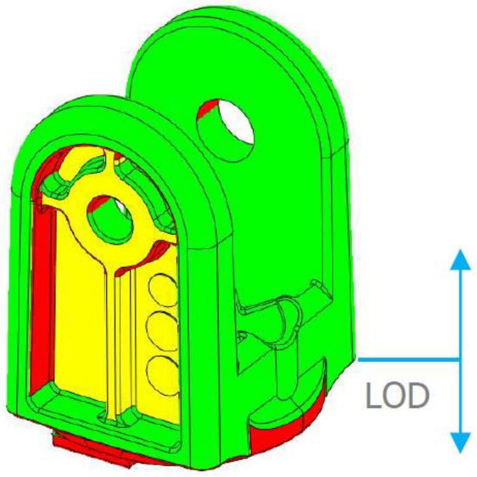


Drag to enlarge

Undercut features

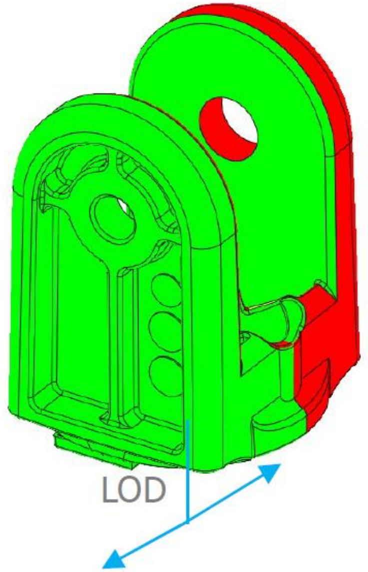


Core/Cavity LOD



Solidworks draft tool

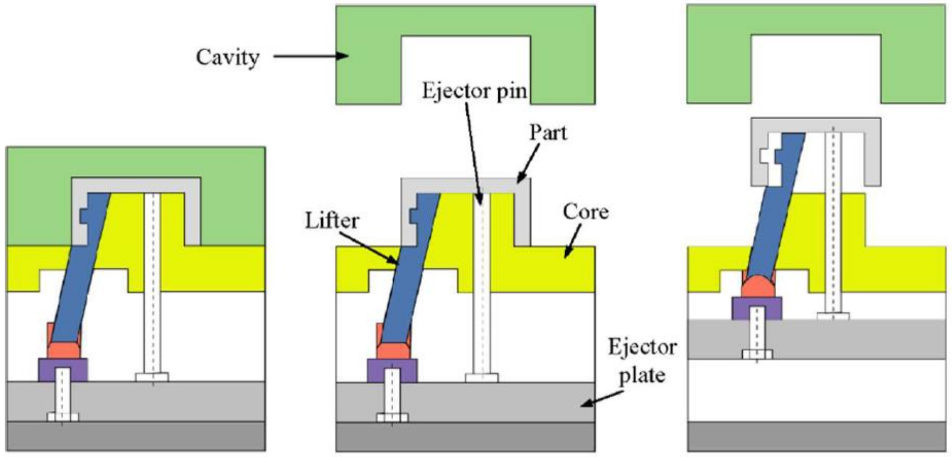
Slider LOD



Up & Away's (or lifters) are a method of forming undercuts on the internal side of the part.

Similar to sliders the up & away's displace laterally relative to the part however unlike sliders the up & away's lift the part off the tool at the same time due to being part of the ejection system.

The up & away's should be drafted based on the direction the slider moves relative to the part not the actual direction of the lifter.

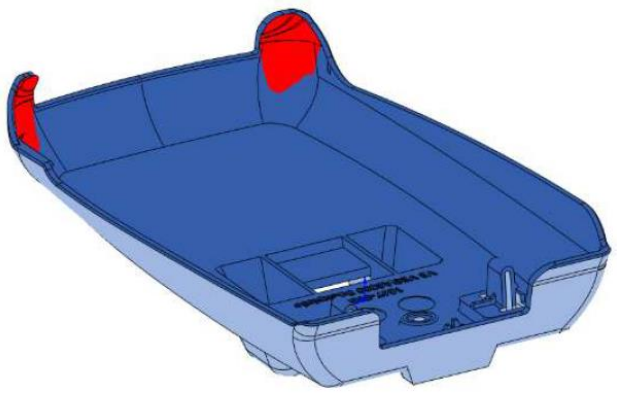


(a) Mold closed

(b) Mold opened: relative motion of cavity

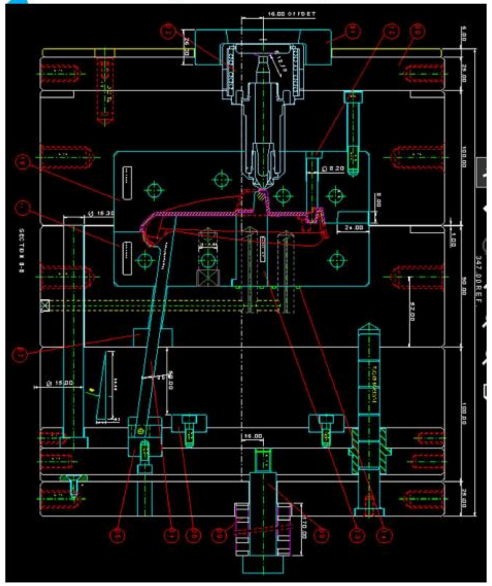
(c) Part ejected as lifter retracts

Edi Uni - I think your model can predict undercuts that are on the core side – if so that will give us a slider count & can can work out cost



Solidworks undercut tool

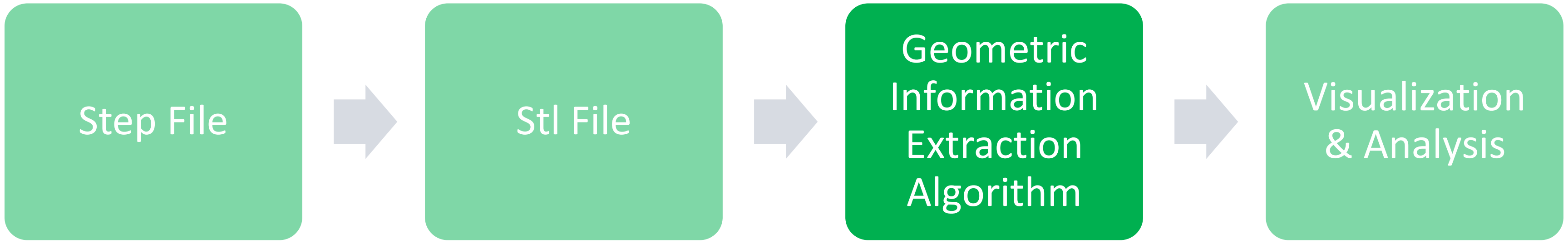
Drag to enlarge



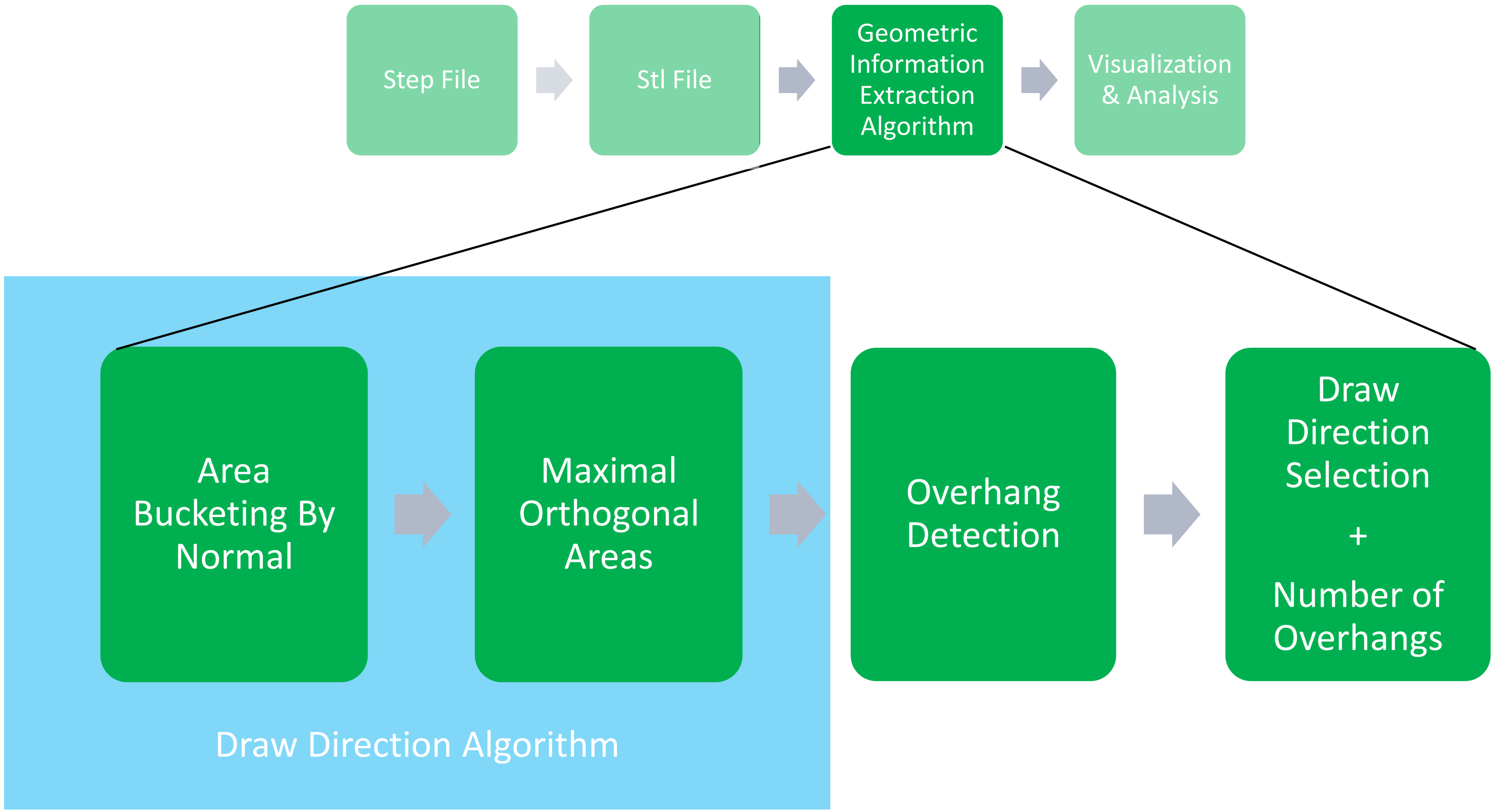
HIGH LEVEL WORKFLOW

Step File → Stl File → Geometric Information Extraction Algorithm → Visualization & Analysis

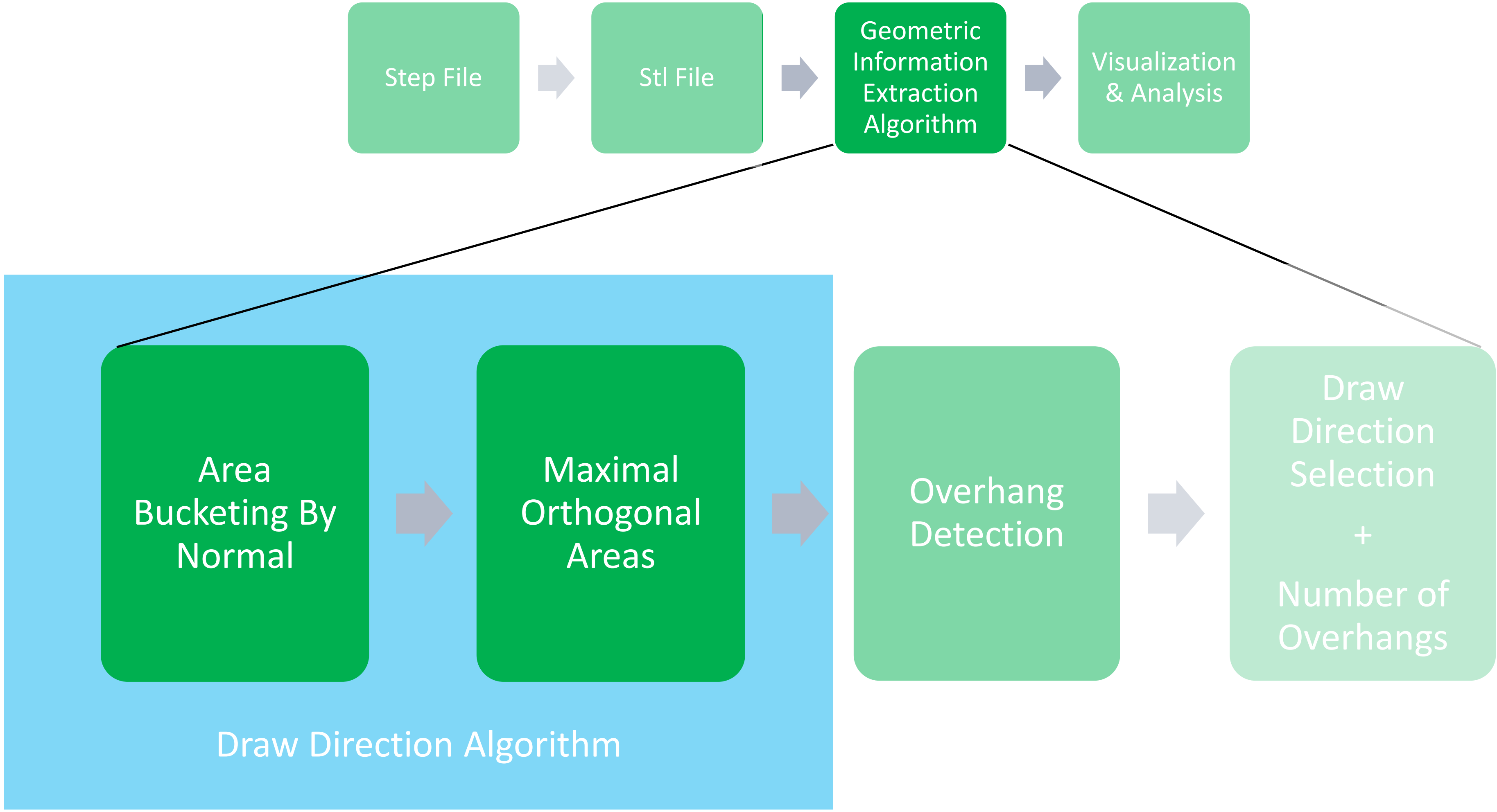
HIGH LEVEL WORKFLOW



GEOMETRIC INFORMATION EXTRACTION ALGORITHM

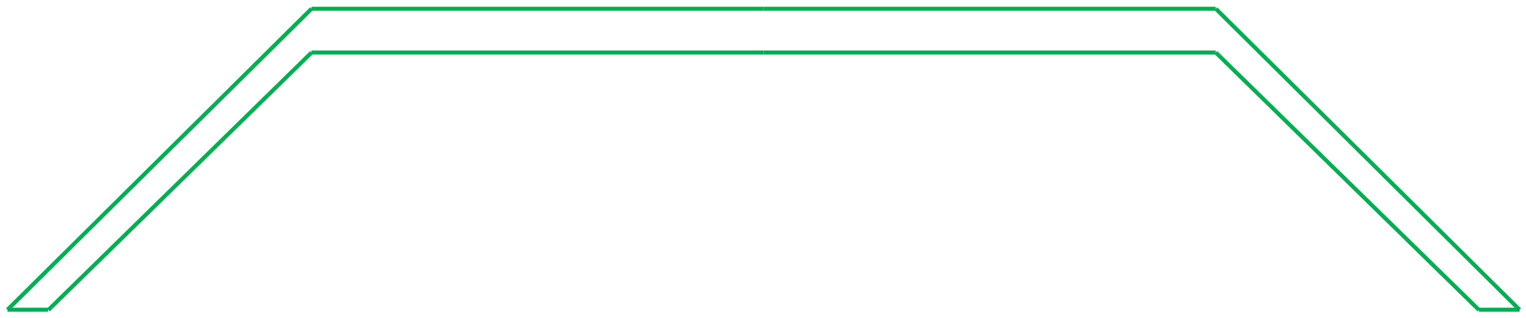


GEOMETRIC INFORMATION EXTRACTION ALGORITHM



MAXIMAL ORTHOGONAL AREAS

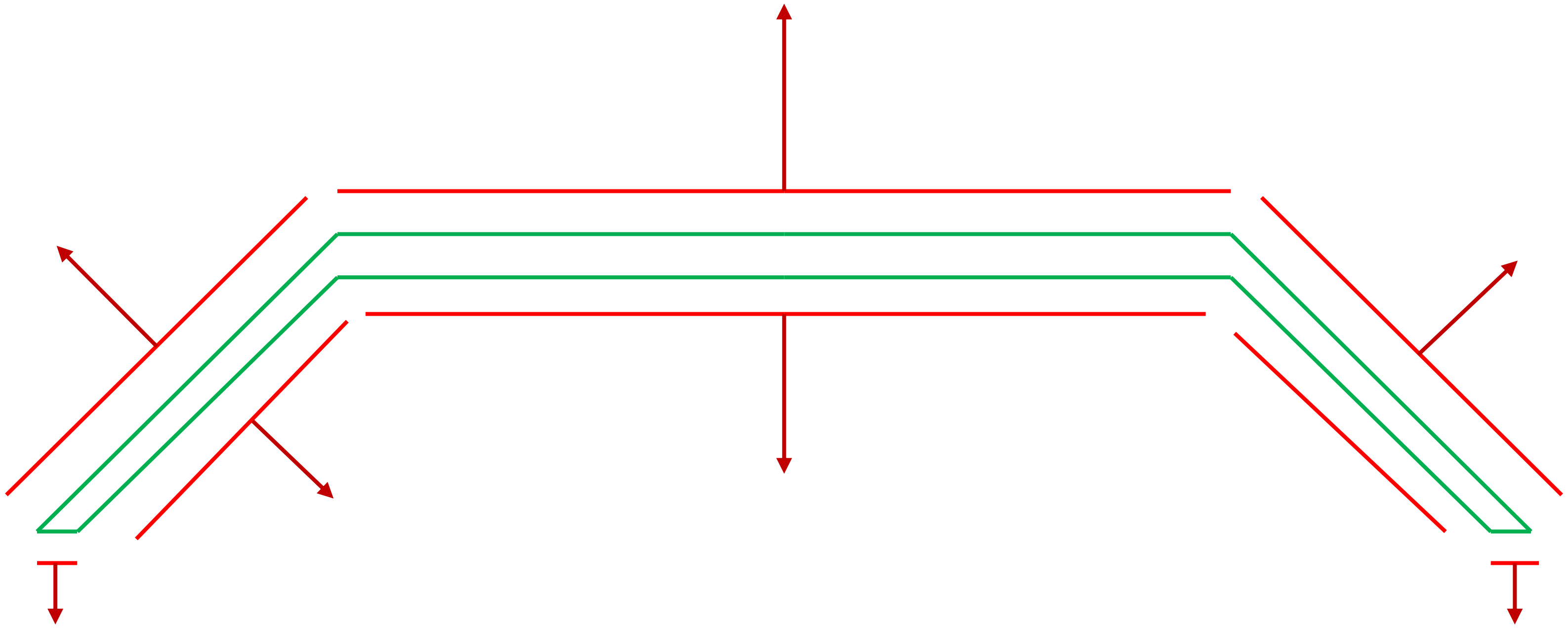
Geometry



MAXIMAL ORTHOGONAL AREAS

Area Bucketing by Normal

Geometry

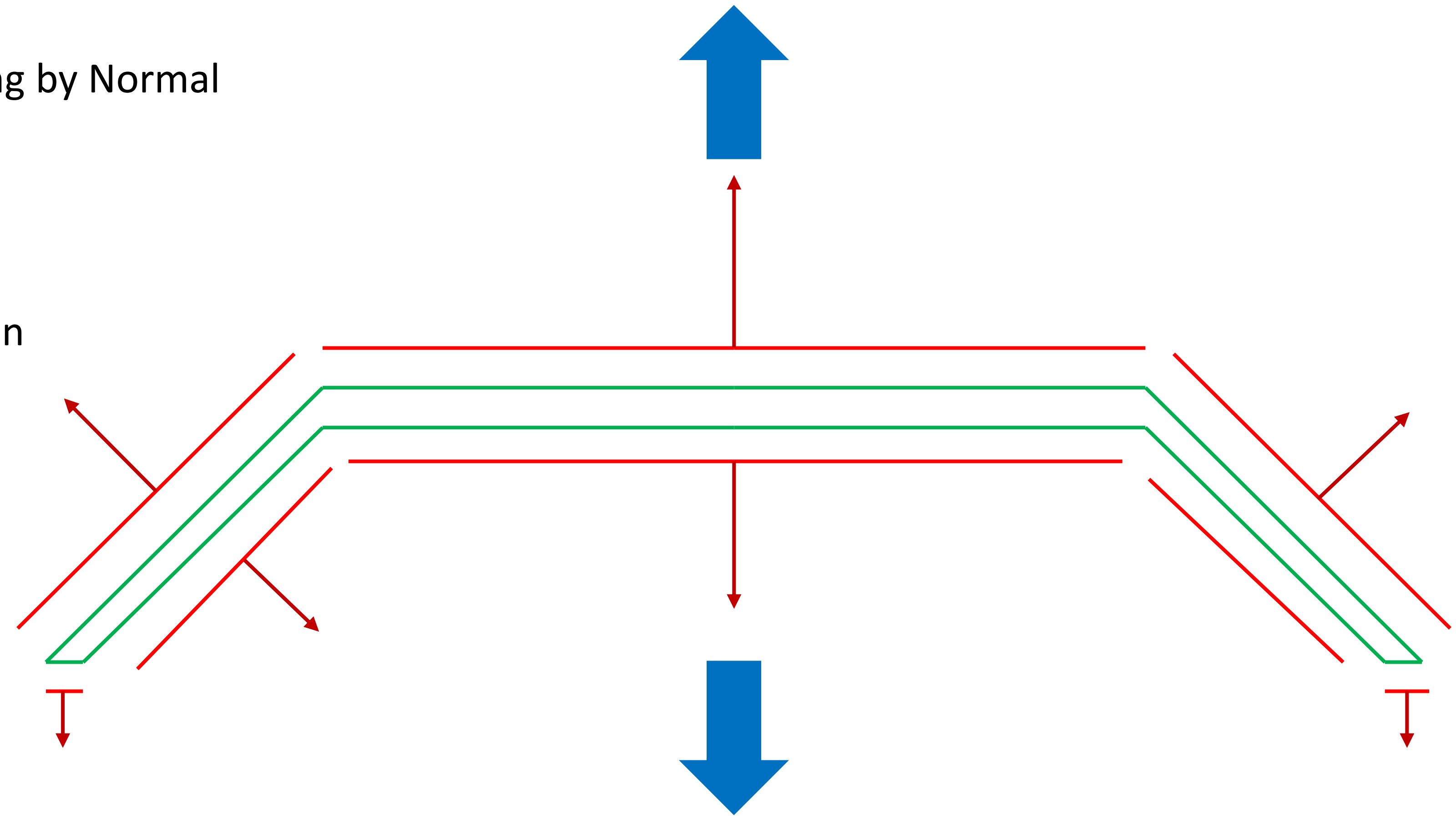


MAXIMAL ORTHOGONAL AREAS

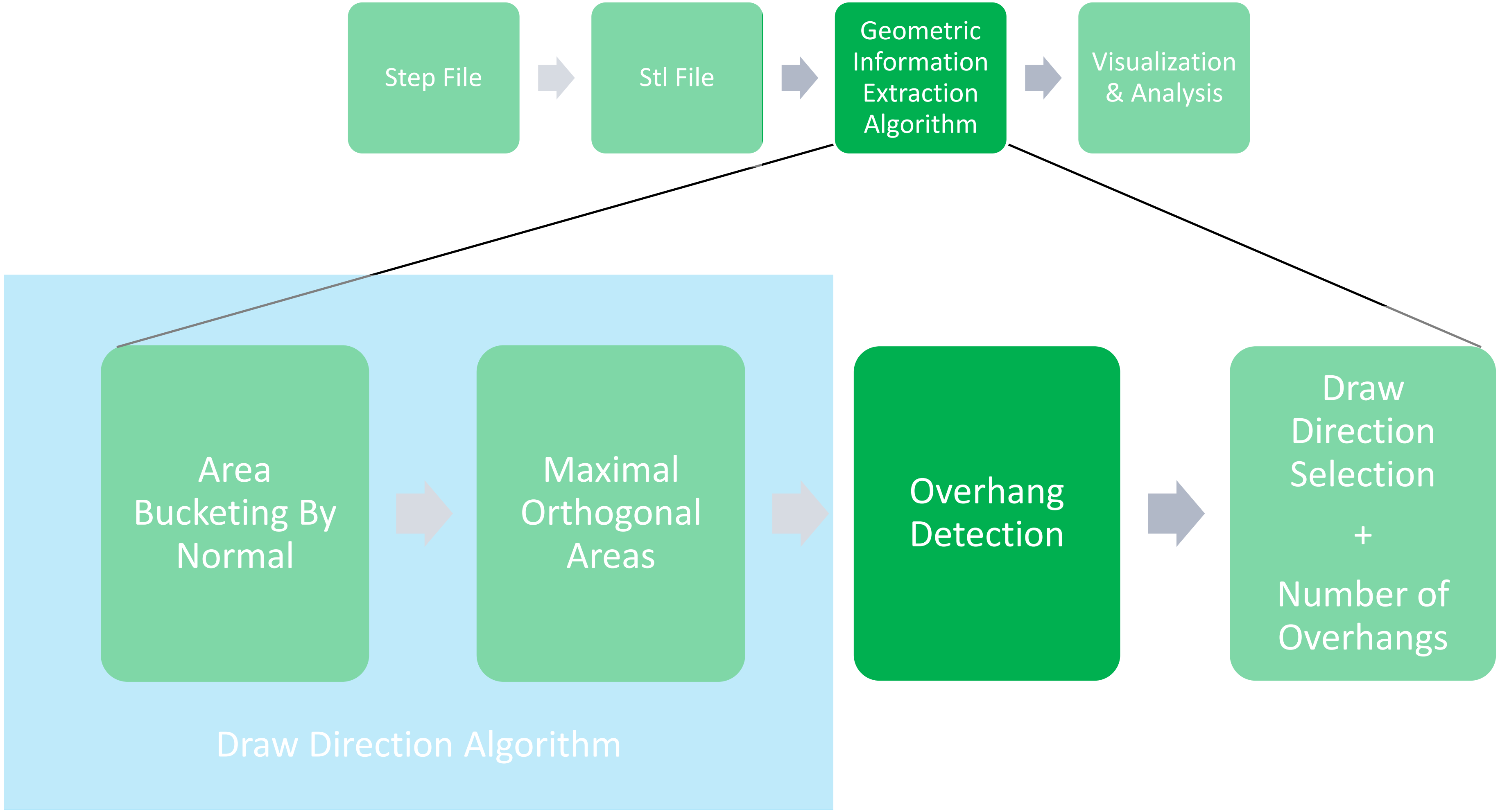
Area Bucketing by Normal

Geometry

Draw Direction



GEOMETRIC INFORMATION EXTRACTION ALGORITHM



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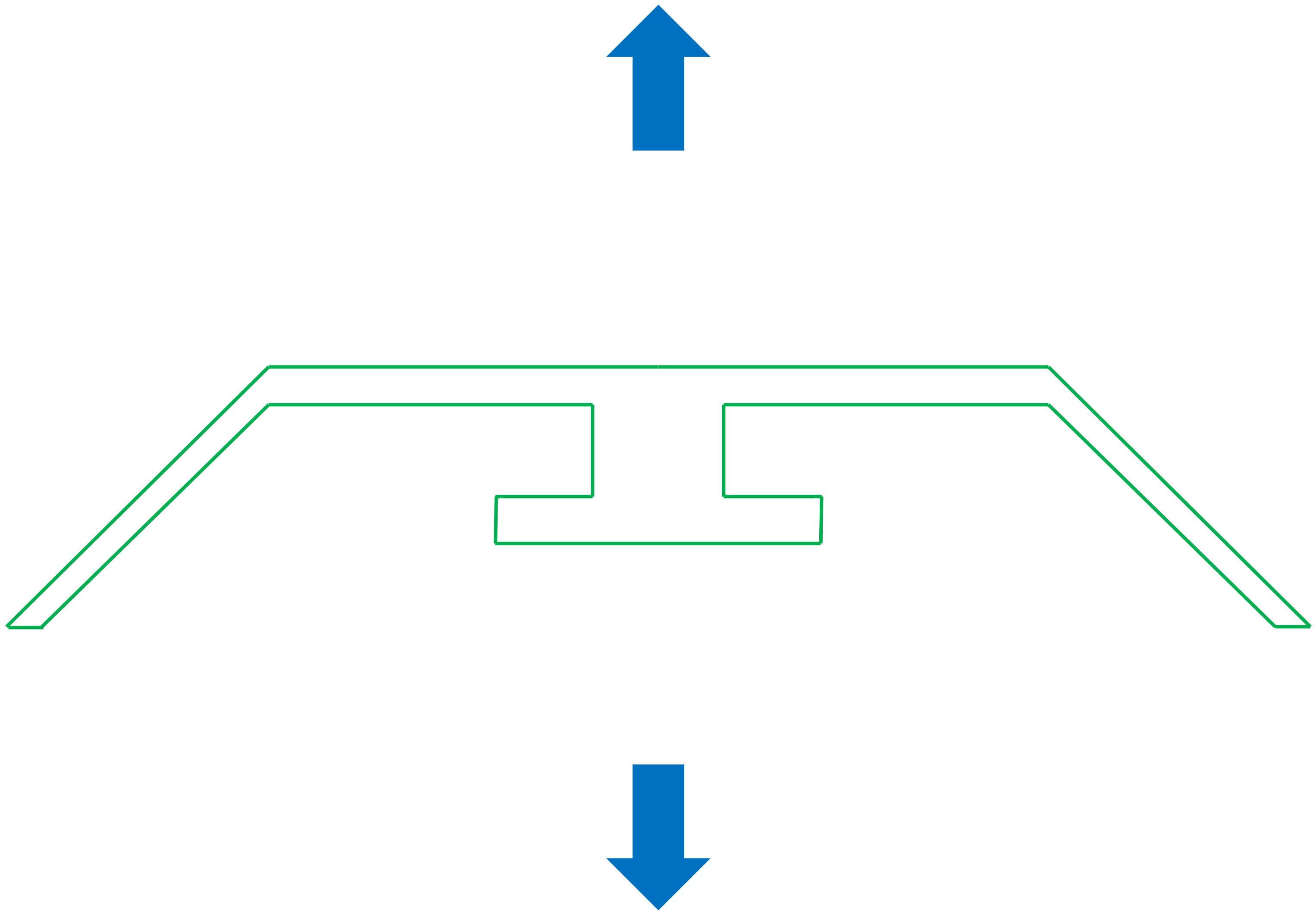
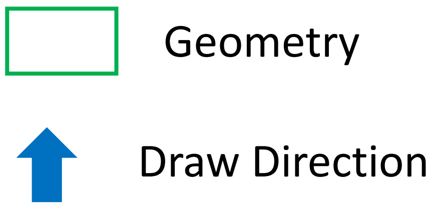
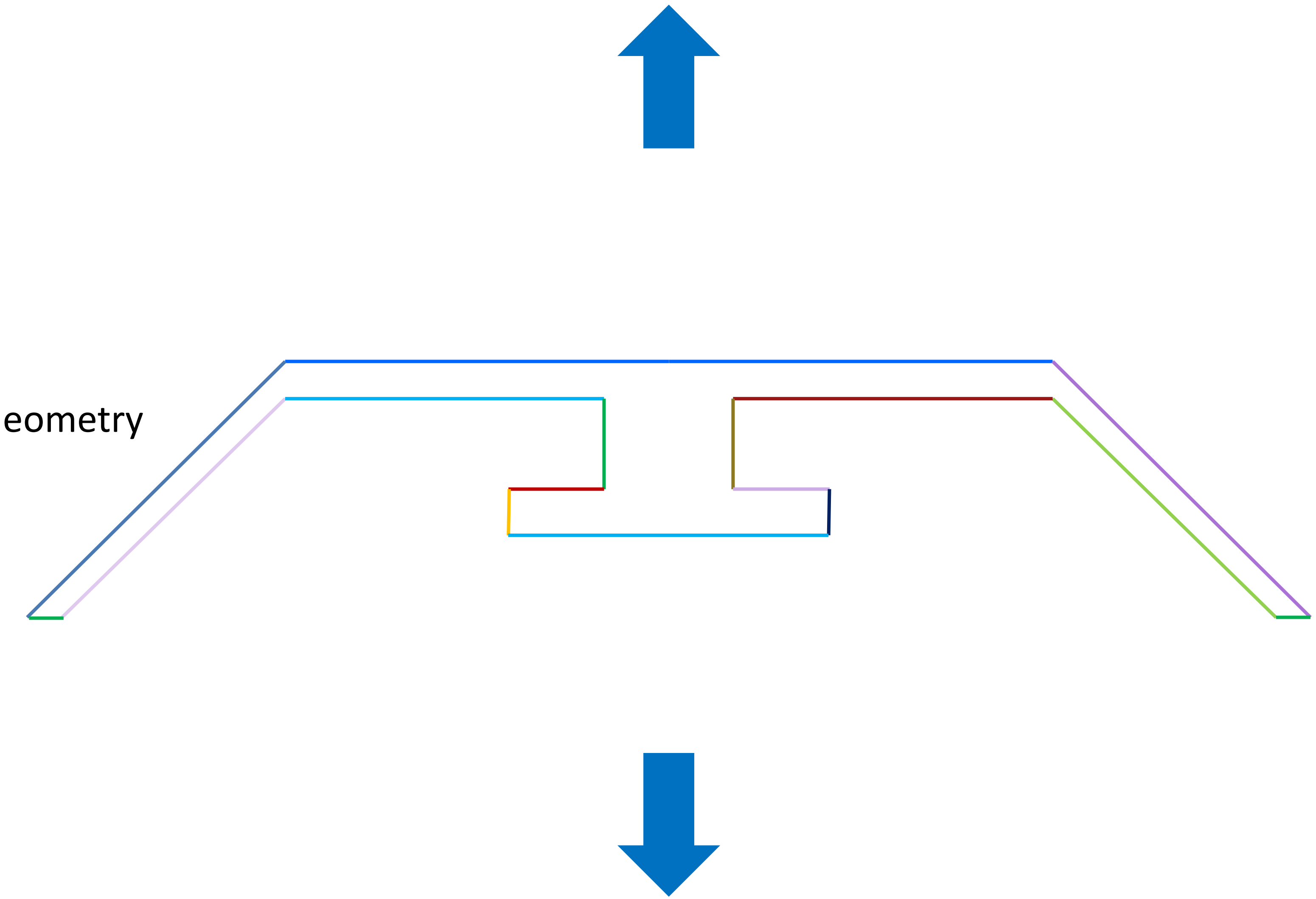
OVERHANG DETECTION





OVERHANG DETECTION



Loose Faceted Geometry

Draw Direction

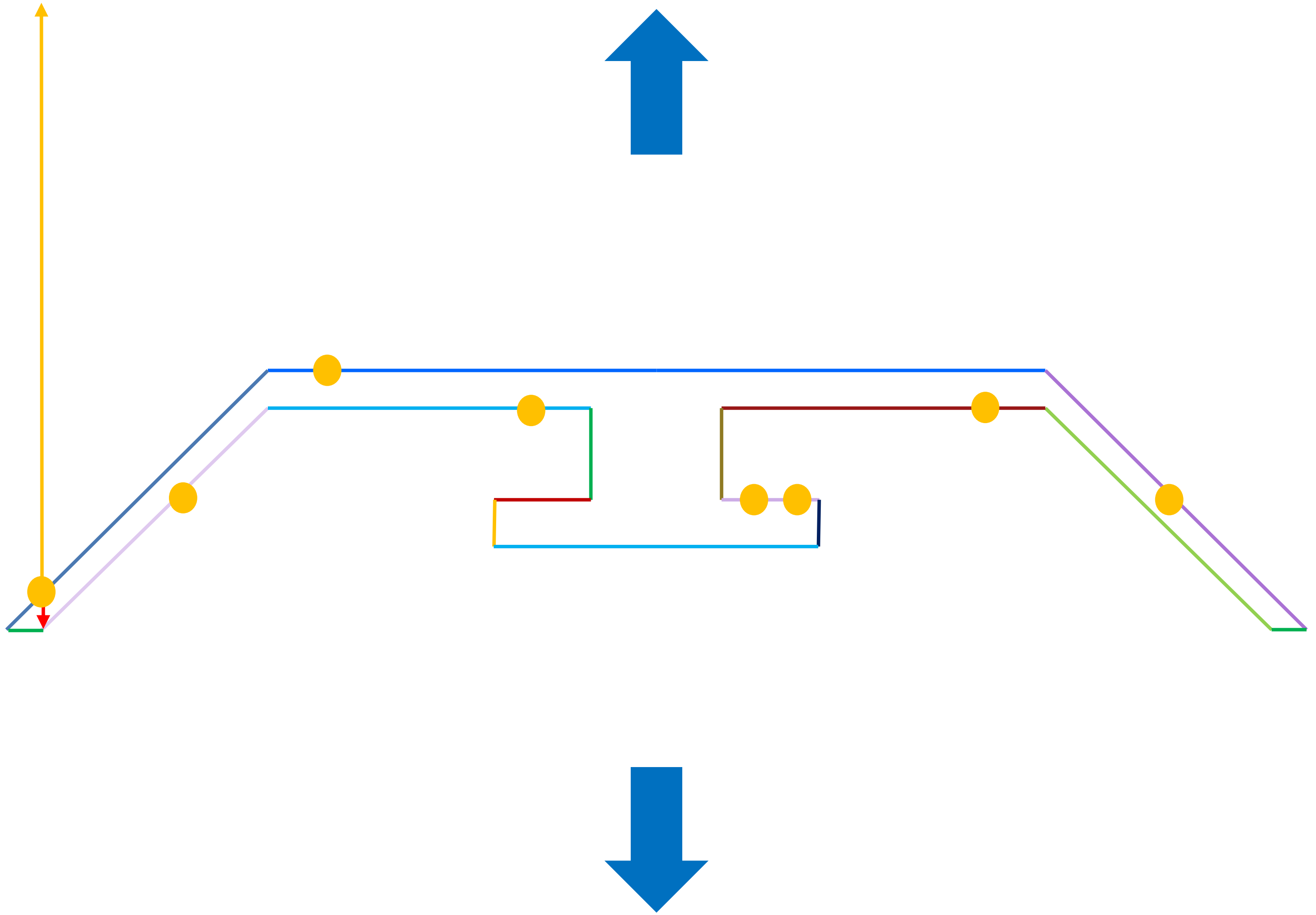
OVERHANG DETECTION

Ray

Sample Point

Loose Faceted Geometry

Draw Direction



Can rays travel to infinity in one of the Draw Directions?

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School of Engineering

OVERHANG DETECTION

Ray

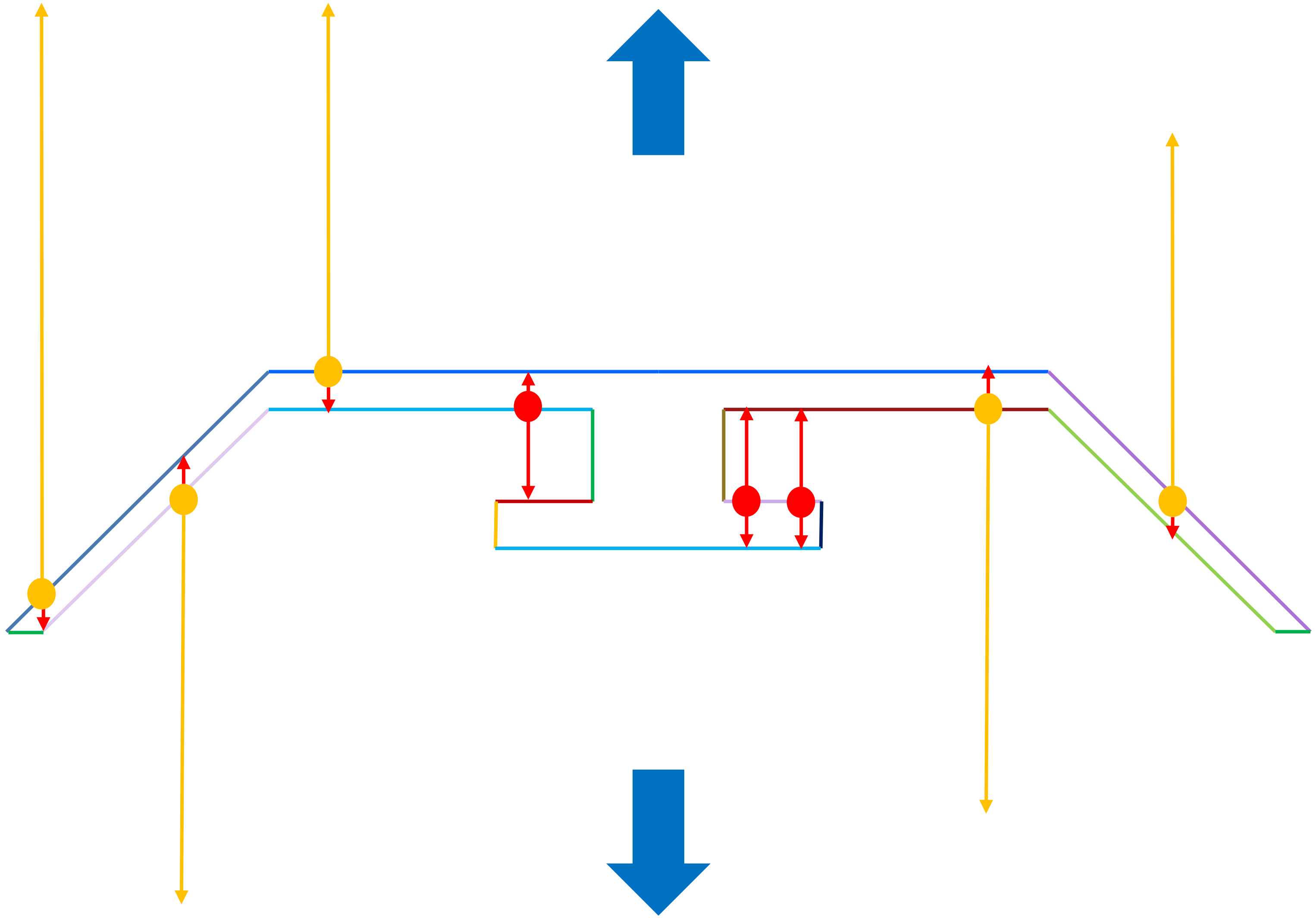
Clashing Ray

Sample Point

Overhanging Sample Point

Loose Faceted Geometry

Draw Direction



An Overhanging Sample point's rays cannot travel to infinity in either Draw Directions

OVERHANG DETECTION

Ray

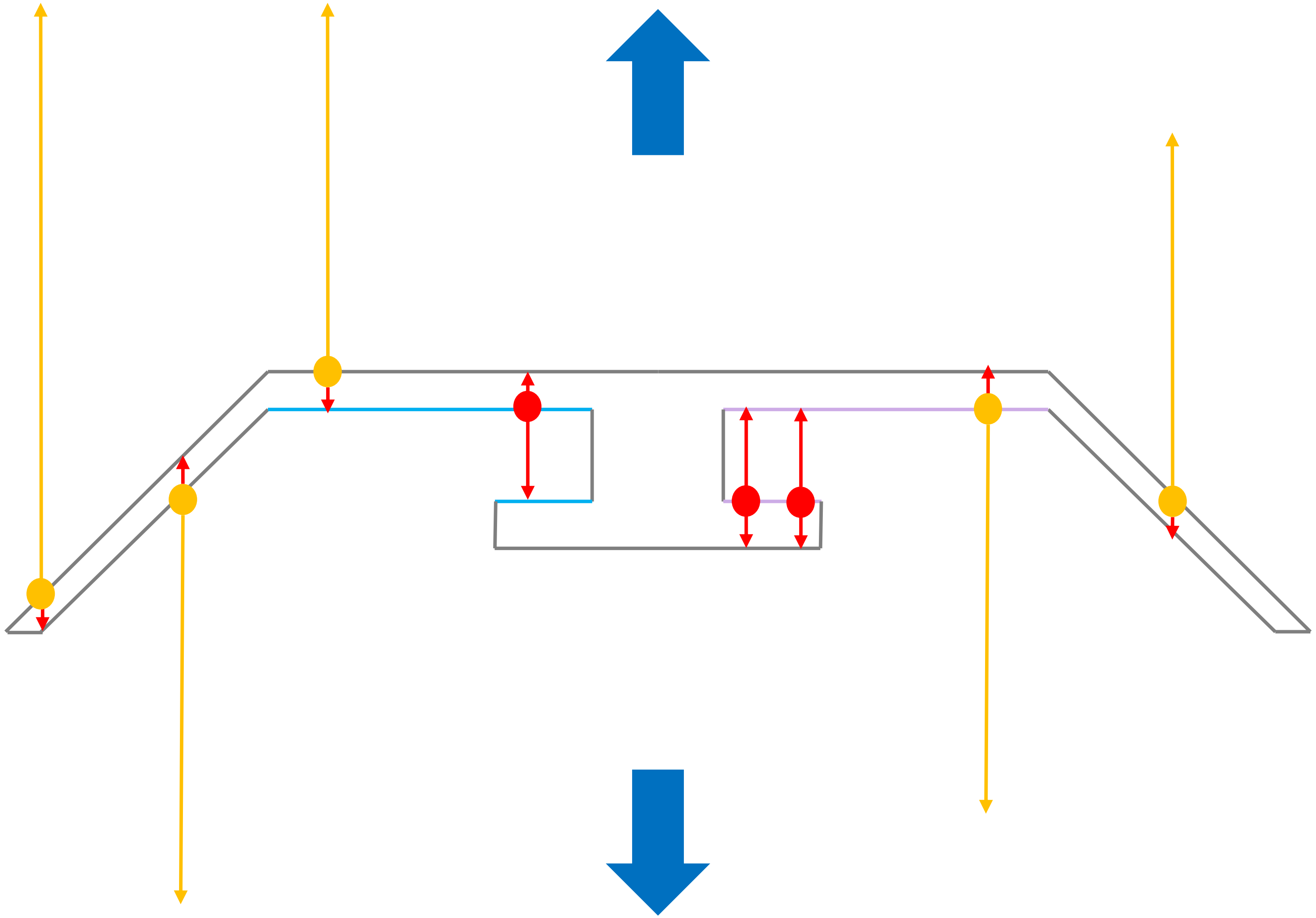
Clashing Ray

Sample Point

Overhanging Sample Point

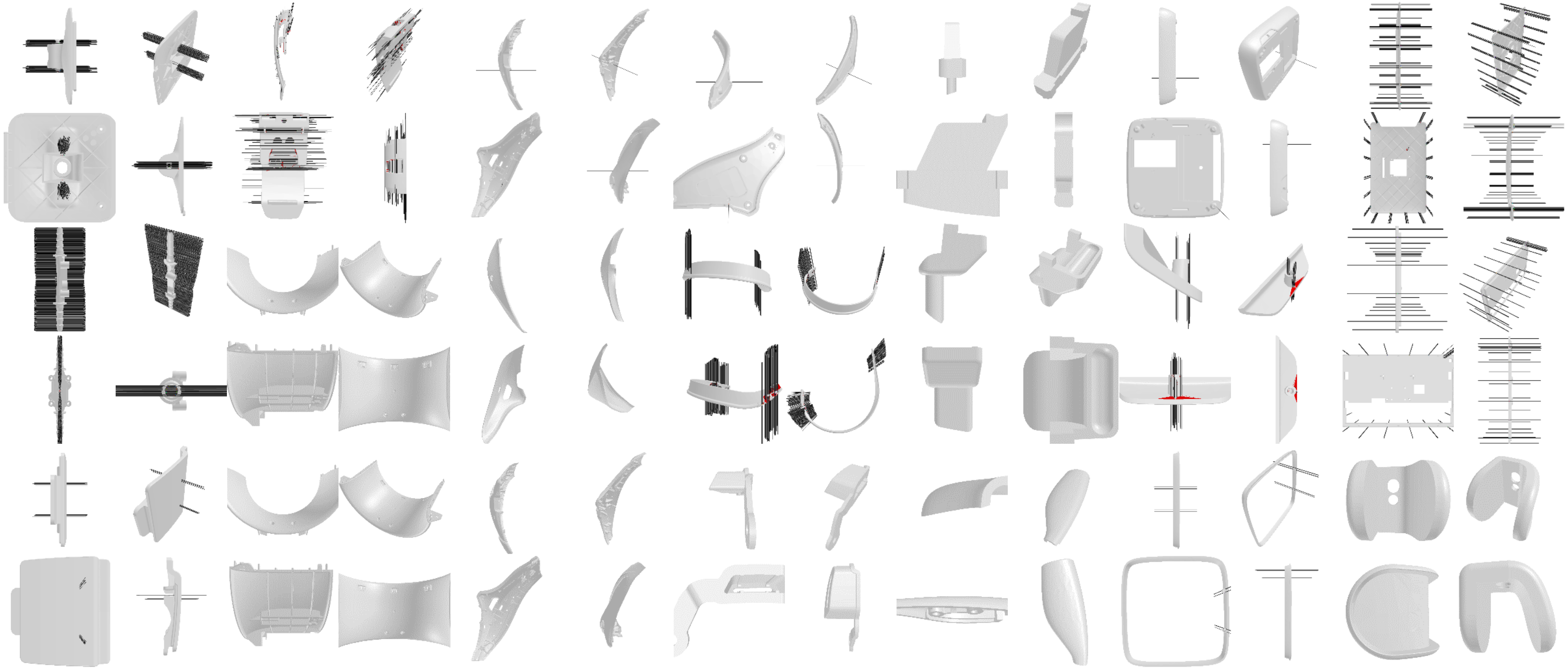
Loose Faceted Geometry

Draw Direction

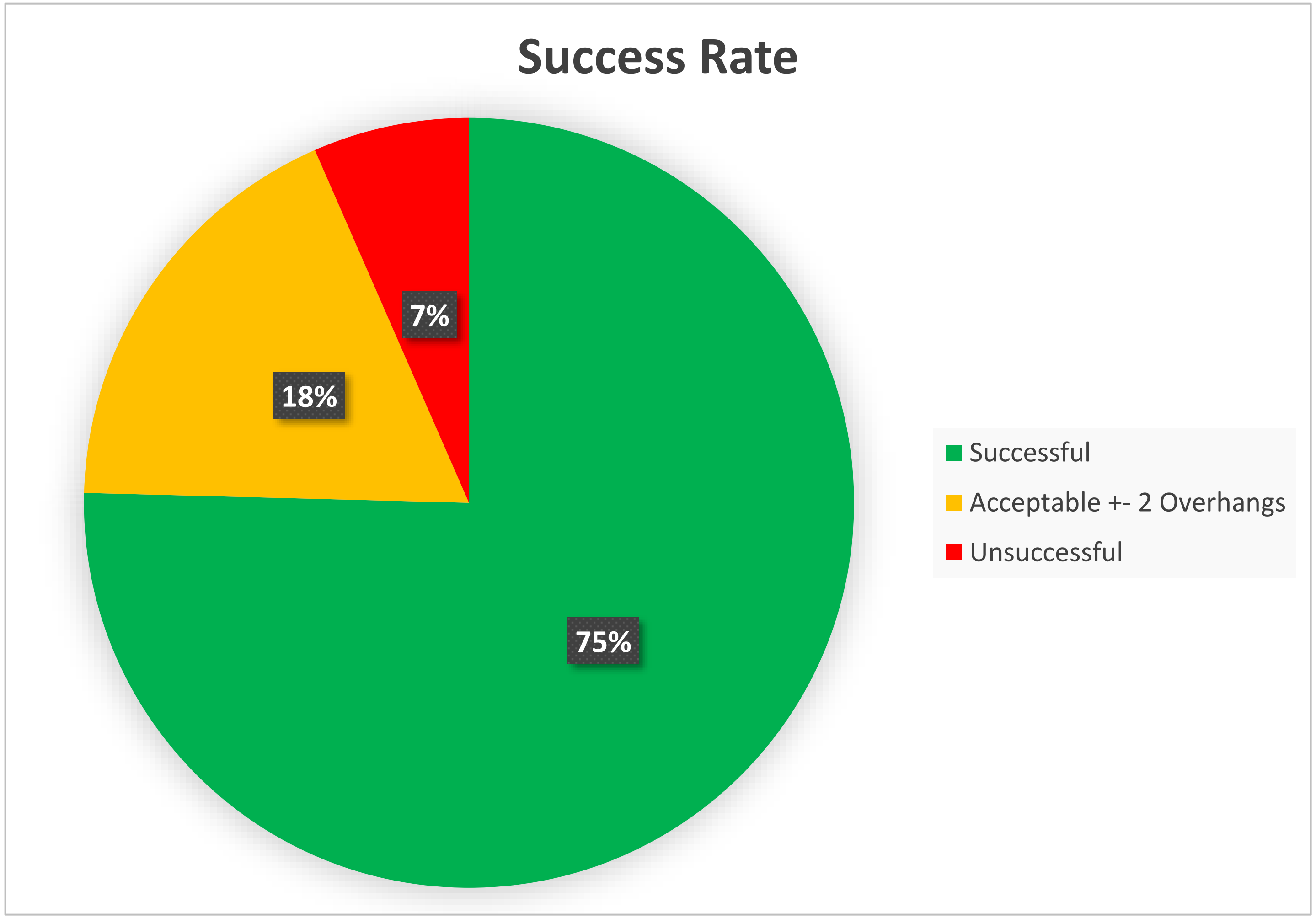


An Overhanging Sample point's rays cannot travel to infinity in either Draw Directions

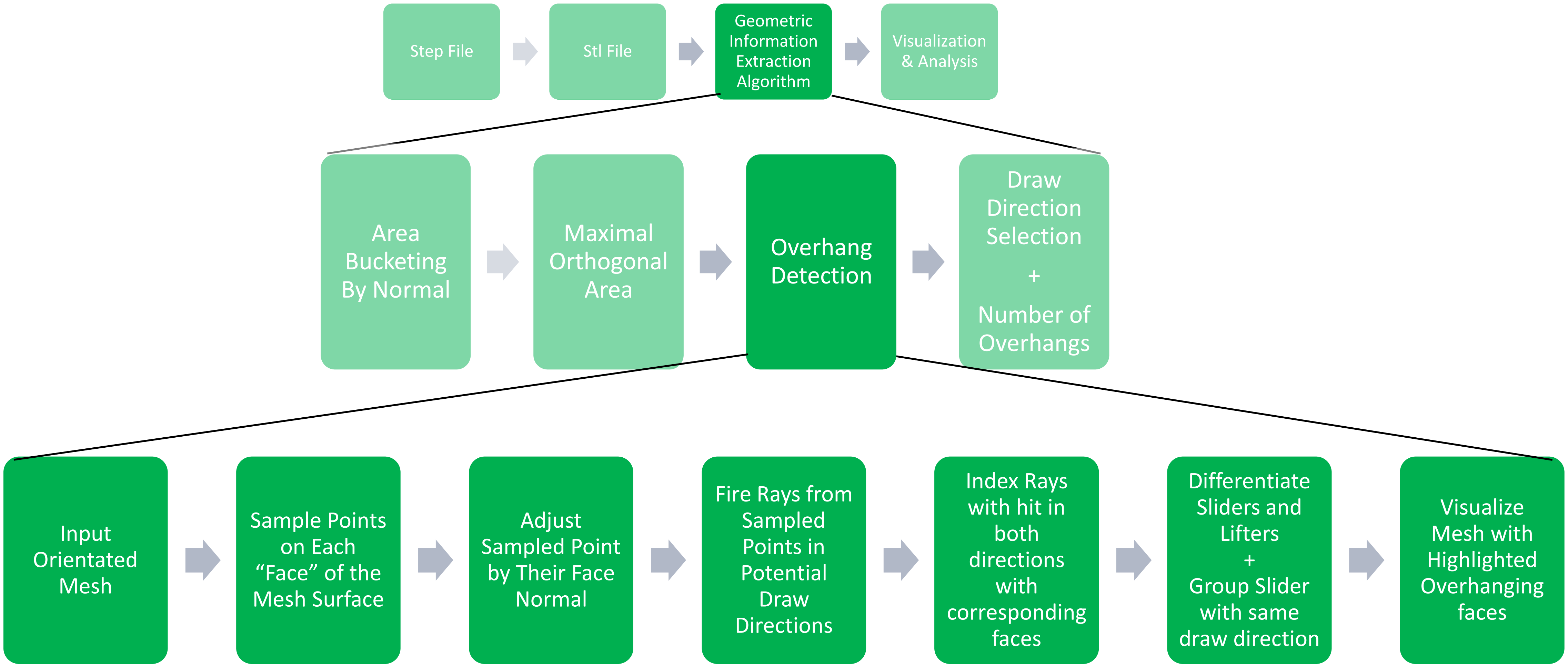
RESULTS



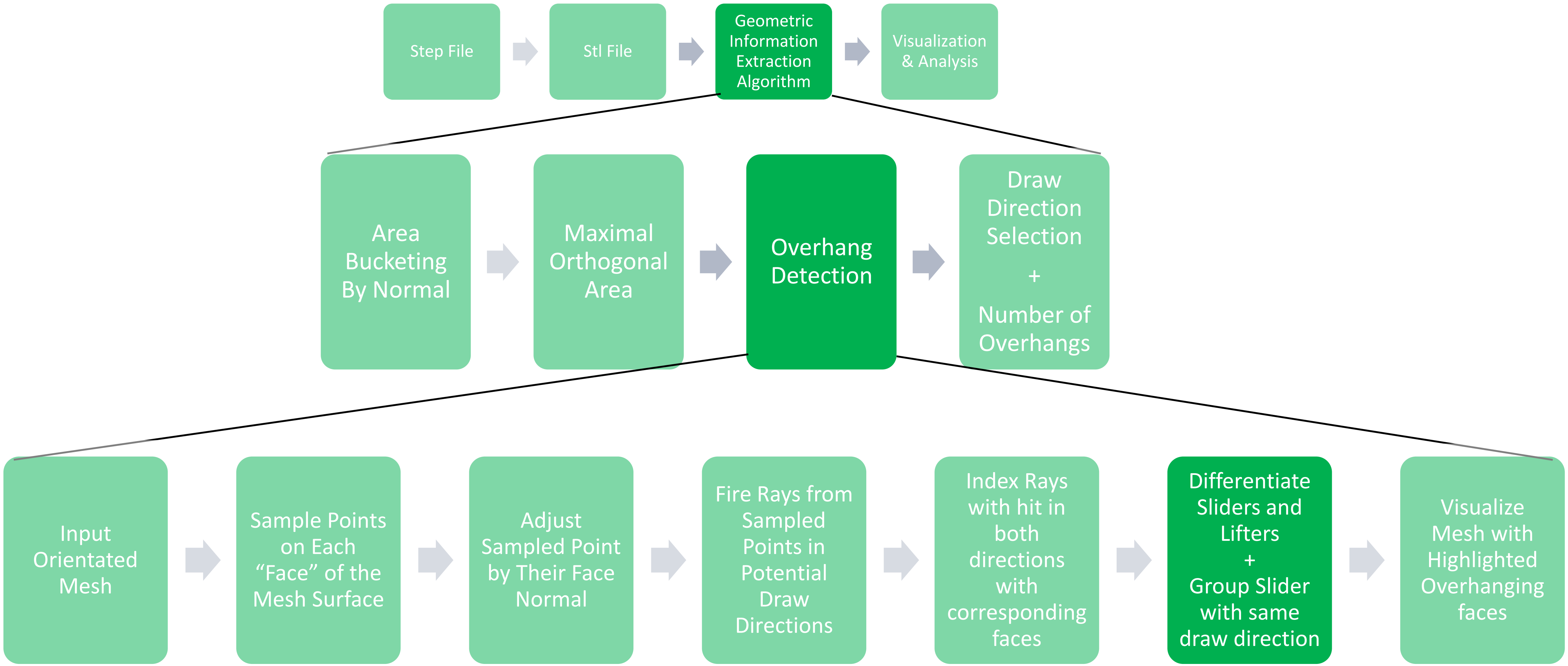
RESULTS


Success Rate
7%
18%
75%
Successful
Acceptable +- 2 Overhangs
Unsuccessful

OVERHANG DETECTION



OVERHANG DETECTION



DIFFERENTIATE SLIDERS AND LIFTERS + GROUP SLIDER WITH SAME DRAW DIRECTION

Find Potential Slider Draw Directions → Check Potential Slider Draw Directions → Group Sliders with common Draw Directions + Count Lifters

OVERHANG DETECTION

Ray

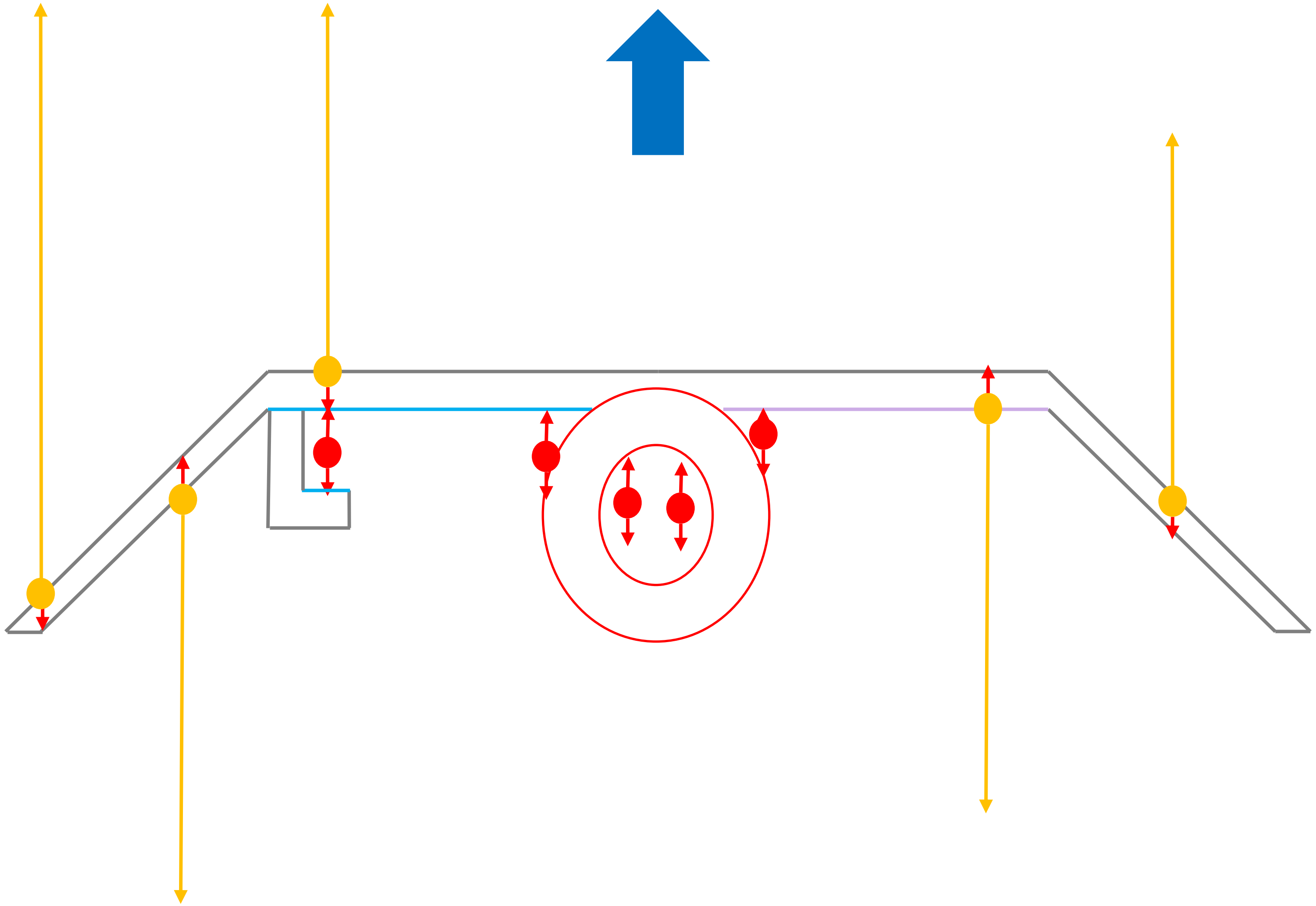
Clashing Ray

Sample Point

Overhanging Sample Point

Loose Faceted Geometry

Draw Direction

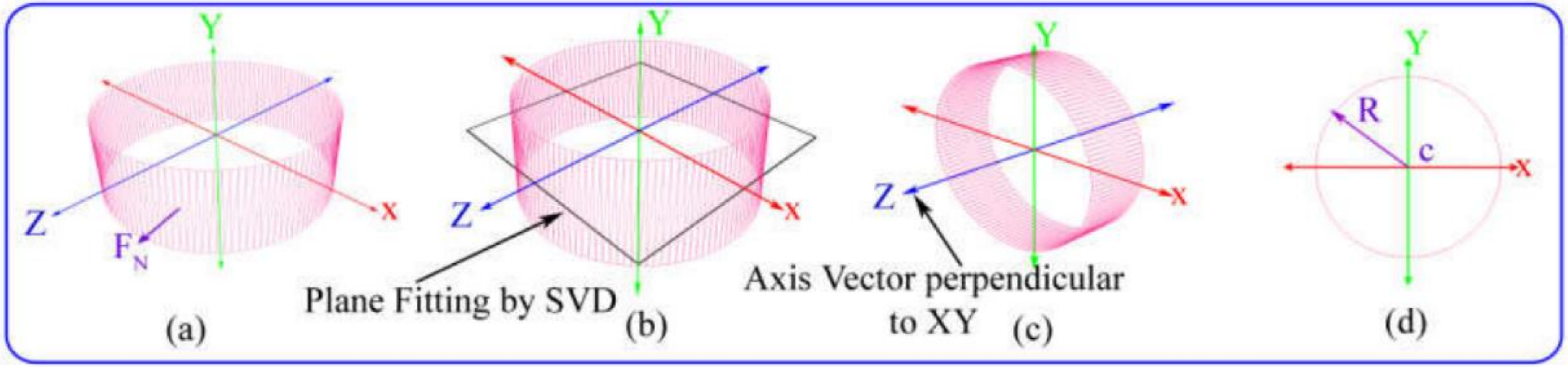


An Overhanging Sample point’s rays cannot travel to infinity in either Draw Directions

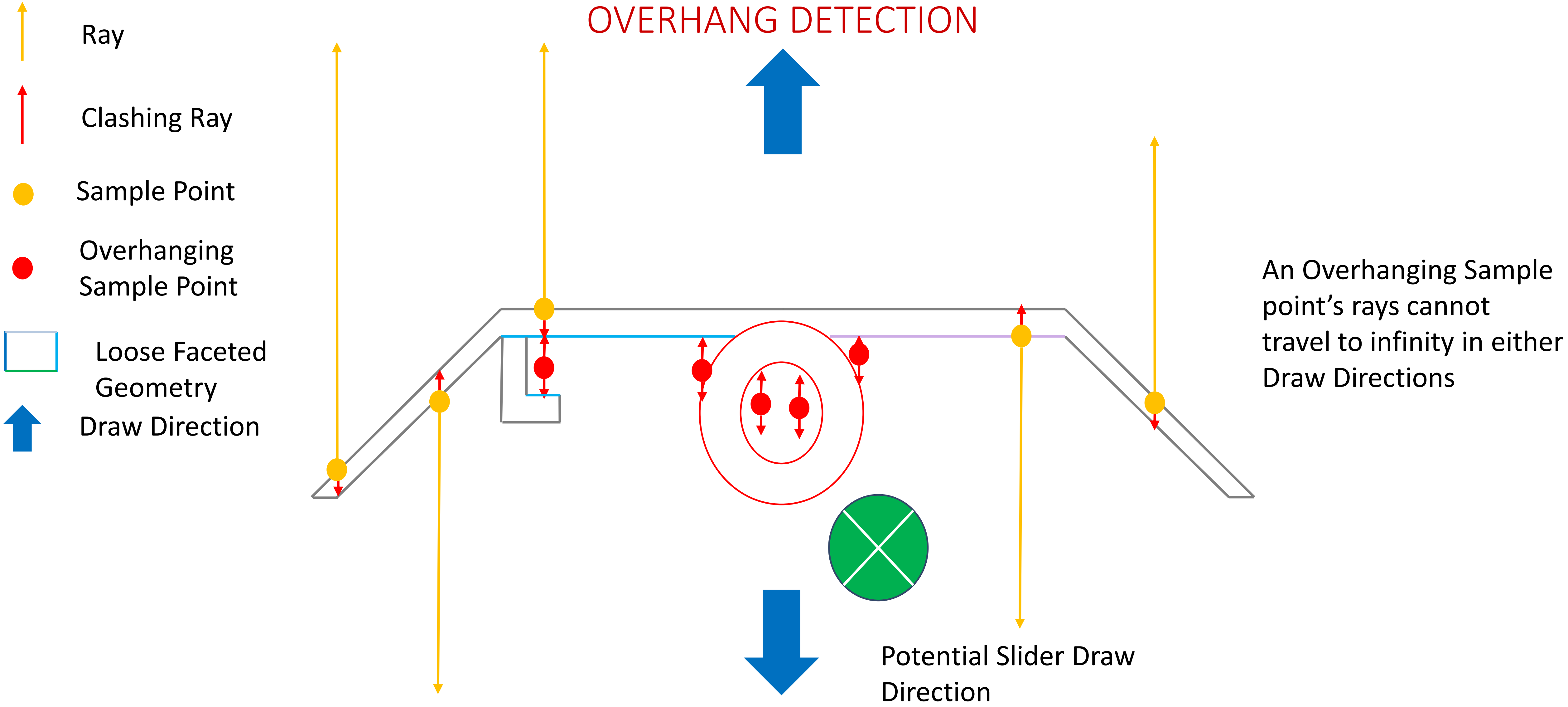
DIFFERENTIATE SLIDERS AND LIFTERS + GROUP SLIDER WITH SAME DRAW DIRECTION

Find Potential Slider Draw Directions → Check Potential Slider Draw Directions → Group Sliders with common Draw Directions + Count Lifters

FIND POTENTIAL SLIDER DRAW DIRECTIONS WITH SINGULAR VALUE DECOMPOSITION



OVERHANG DETECTION



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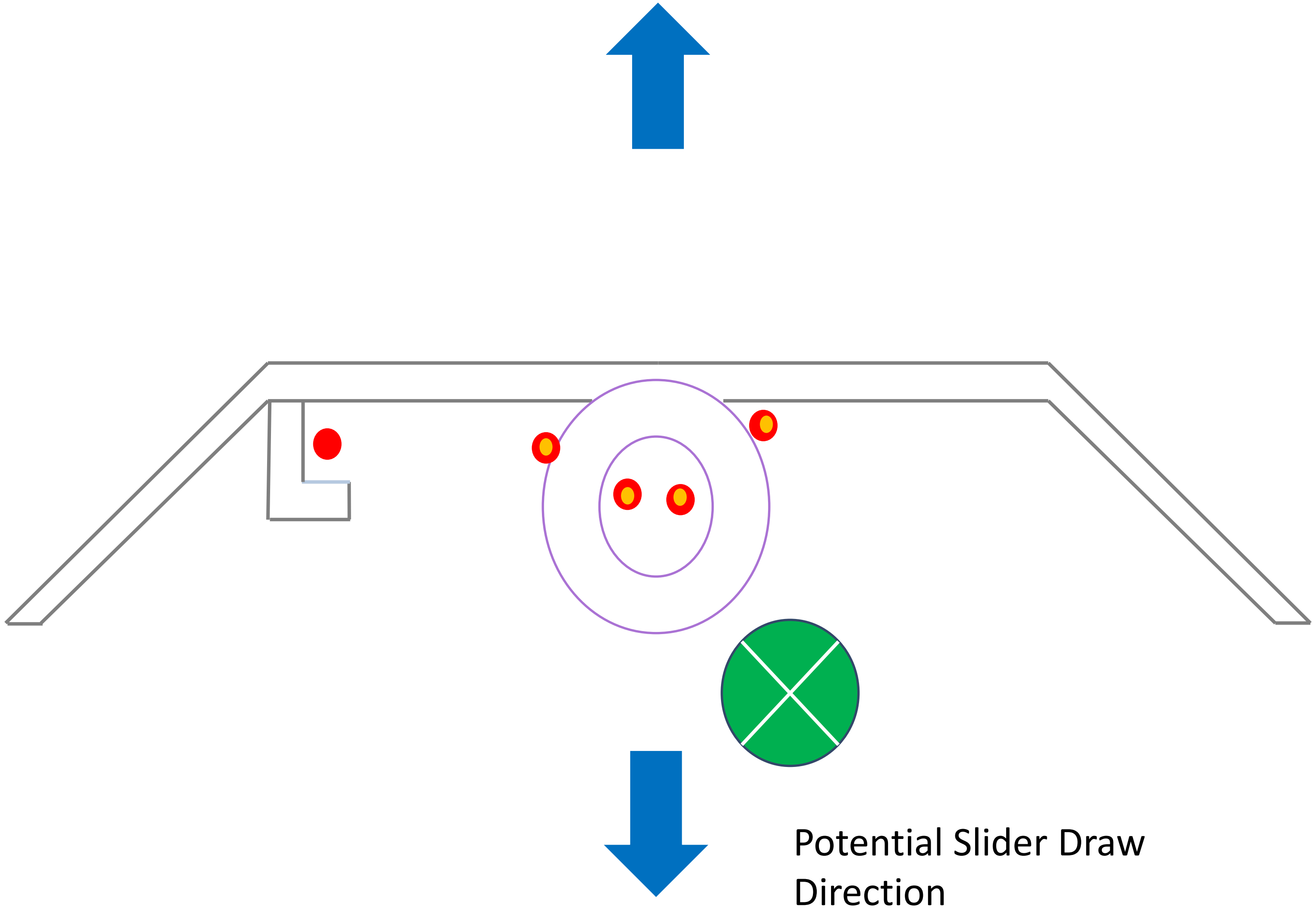
Draw Direction



An Overhanging Sample point’s rays cannot travel to infinity in either Draw Directions

DIFFERENTIATE SLIDERS AND LIFTERS + GROUP SLIDER WITH SAME DRAW DIRECTION

Find Potential Slider Draw Directions → Check Potential Slider Draw Directions → Group Sliders with common Draw Directions + Count Lifters

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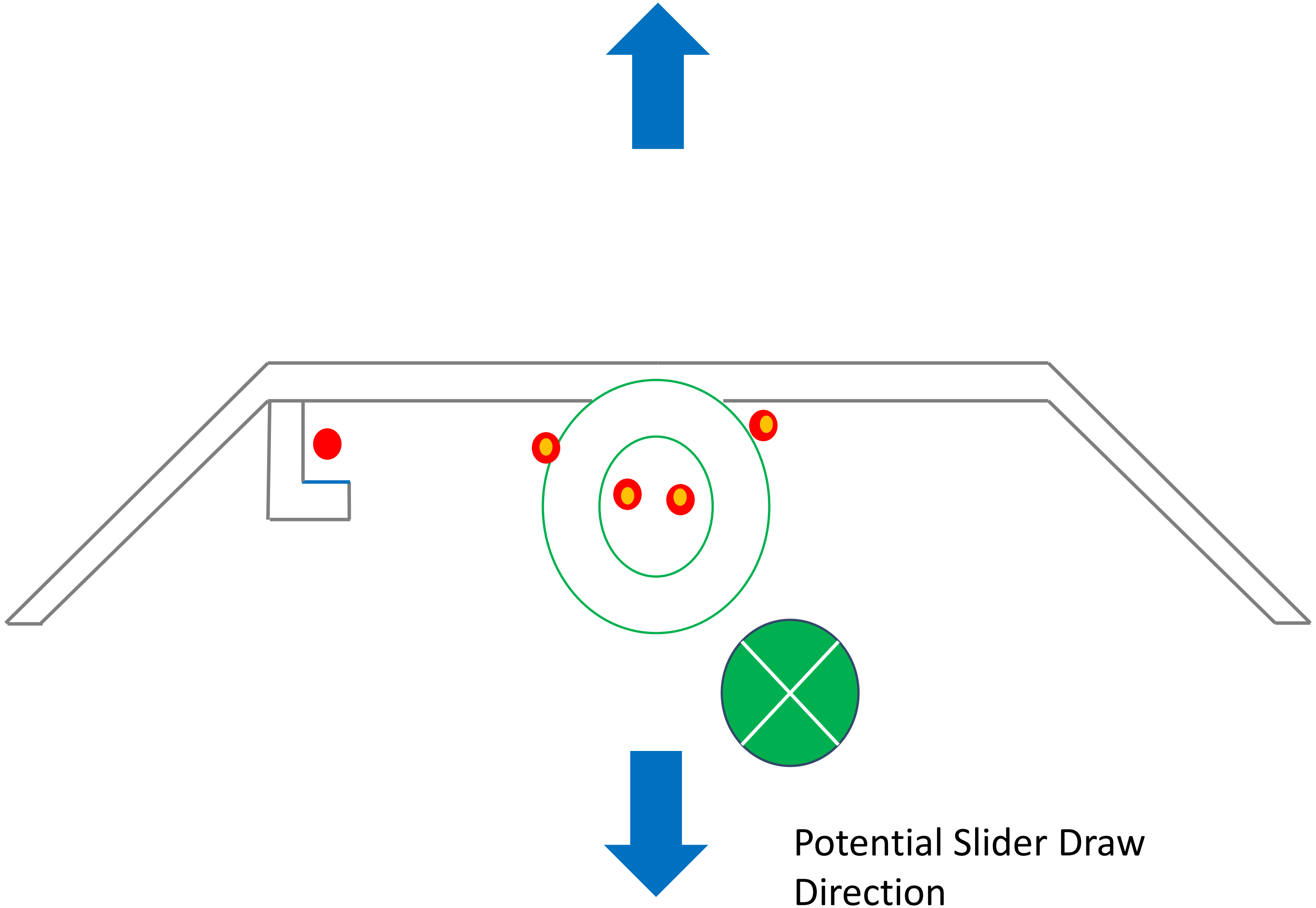
Loose Faceted Geometry

Draw Direction

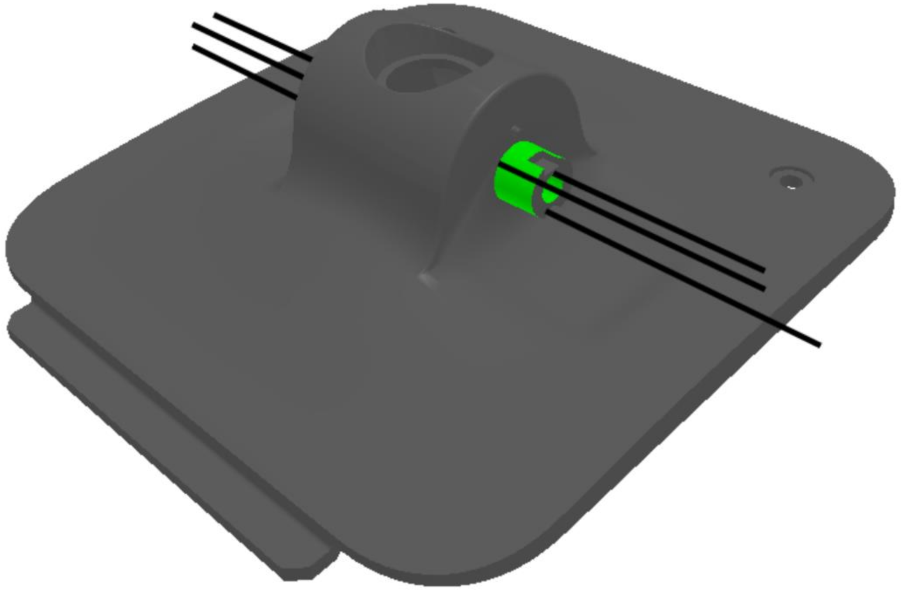


An Overhanging Sample point’s rays cannot travel to infinity in either Draw Directions

Potential Slider Draw Direction


C:/Users/Justin Savage/PycharmProject/i4pd003/overhang_detection.py
DRAW Direction: BLUE
TechSmith®
MADE WITH CAMTASIA FREE TRIAL
Type here to search
17°C Sunny
ENG
10:58
22/09/2021

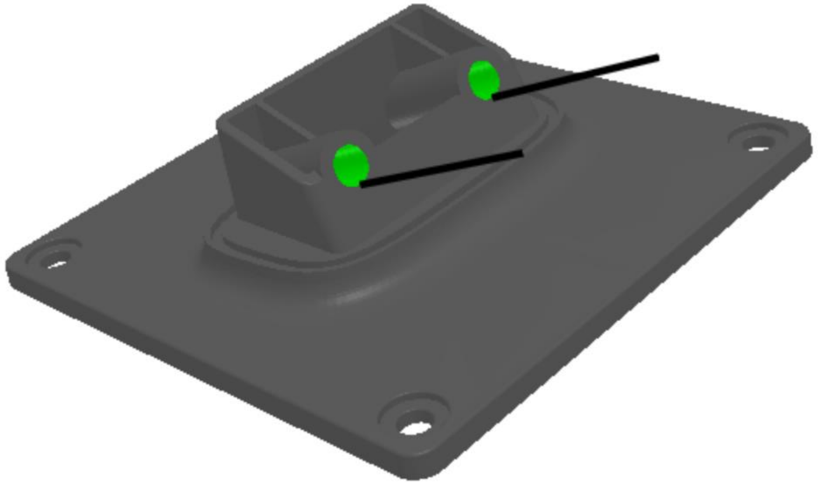
1016-0018-MALE HINGE-REV03



Algorithm: 2 Sliders

Quote: 2 sliders

1016-0049-CUSTOMER SCREEN VESA COVER-REV02



1 Slider

Quote 1 slider

PRICE PREDICTION MODELS

Dataset

- Dataset containing 91 parts which combines:
  - i4pd provided data in “2021-0422-Simple Database Plastic parts-Rev01.xlsx” spreadsheet along with corresponding CAD files
  - ShapeSpace Signatures for the CAD files
  - Number of lifters and sliders predicted
- 56 “FAMILYTOOL” parts have to be removed due to the difference in manufacturing between these tool type
- 1 further part had to be removed due to faulty mesh generated by the CAD file
- The resulting dataset used to generate the models consists of ***34 parts***

Dataset

- Heavily skewed dataset: log or square root transformations are applied to certain signature values
- Data from i4pd spreadsheet encoded into categorical variables:
  - *large_part_quantity*: If the part had a quote volume greater than 500.
  - *smooth_cavity_finish*: If a tool for a part had a smooth cavity finish.
  - *is_material_commodity*: If the material contains the string “POLYPROPYLENE”, “PPC” or “PPH”.
  - *requires_secondary_op:* If a part required a secondary operation.

Model Pipeline

The models work through the following pipeline:

1. Values for the features are calculated from the inputs given and through the geometric analysis of a CAD file
2. The features and target are created and transformed as required.
3. Features are then input into the model and a value is predicted for the log value of the price
4. The predicted value is then the transformed back to get the price

Model Evaluation

- Create two separate prediction models:
  - Predict the cost of the tool required to create a part
  - Predict the cost to manufacture a part
- Both prediction models use the a linear regression model with L2 normalisation
- Input features determined through a mixture of hierarchical clustering, analysis for colinearity and recursive feature selection
- Performance of the models was measured by the mean absolute error (MAE) on a random subset split off from dataset
- Hyperparameters and model selection was carried out by using cross validation of the dataset

Model Results

Tool Cost Prediction:

- Uses as inputs:
  - *"COMPACTNESS'*
  - *"SURFACE AREA"*
  - *"predicted_num_sliders"*
  - *"requires_secondary_opp"*
  - *"smooth_cavity_finish"*

Price Cost Prediction:

- Uses as inputs:
  - *"ASPECT RATIO 0"*
  - *"VOLUME"*
  - *"large_part_quantity"*
  - *"is_material_commodity"*
  - *"requires_secondary_opp"*

Estimator	Part Mean Absolute Error (£)	Tool Mean Absolute Error (£)
Expert Human	0.65	5336.88
HWH Early Estimator	1.10	3185.63
EdU CAD Estimator	0.51	2847.13
i4pd Phy. Mod. Estimator	0.66	4420.50

Background

- Theorem already had close relationship with very large US Automotive OEM
- PLM infrastructure based on Teamcenter
- Current infrastructure has very high utilisation rates inhibiting innovation
- Desire to engage with smaller, innovative companies for microservices for specific problems in design programs

Consortium

- Theorem 25+ years of CAD converters and VR, AR and MR products for engineering OEMs
- ShapeSpace develop CAD and analytics libraries focused on manufacturing to enable large scale reasoning about part geometry, BoMs and product structure

ShapeSpace

Theorem Solutions

Problem 1: Identifying significant part changes

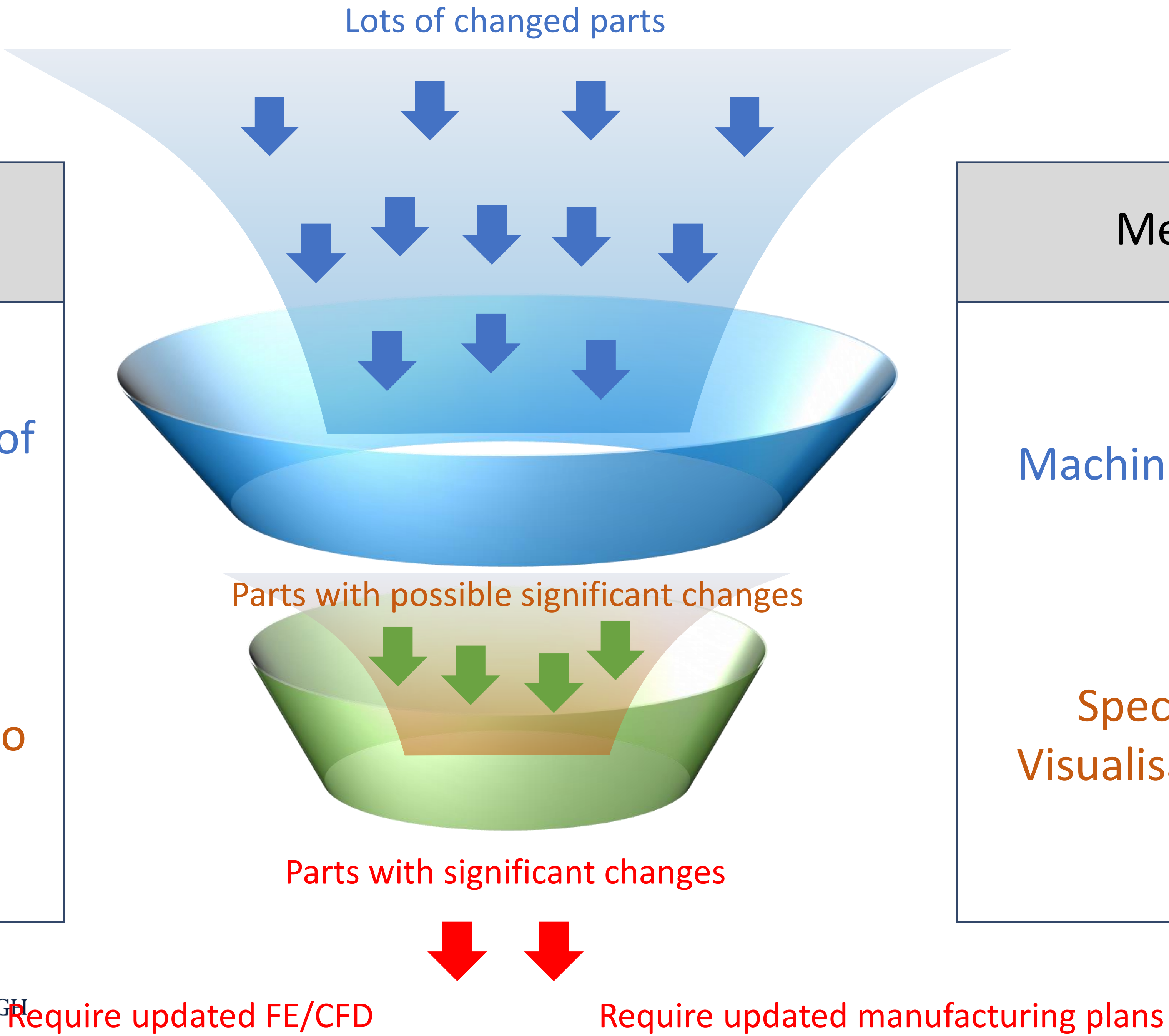
Background

- During a vehicle design programme parts can change significantly
- CAE and manufacturing teams need finite element models and process plans kept up-to-date

Issues

- 200+ models can change per day per program
- 50+ program active
- Somebody’s job to manually assess changes
- Very time consuming and tedious

Stage	Method
Automatic filtering of changes	Machine Learning
Expert using visualisation tool to inspect changes	Specialised Visualisation tool



Problem 1: Identifying significant part changes

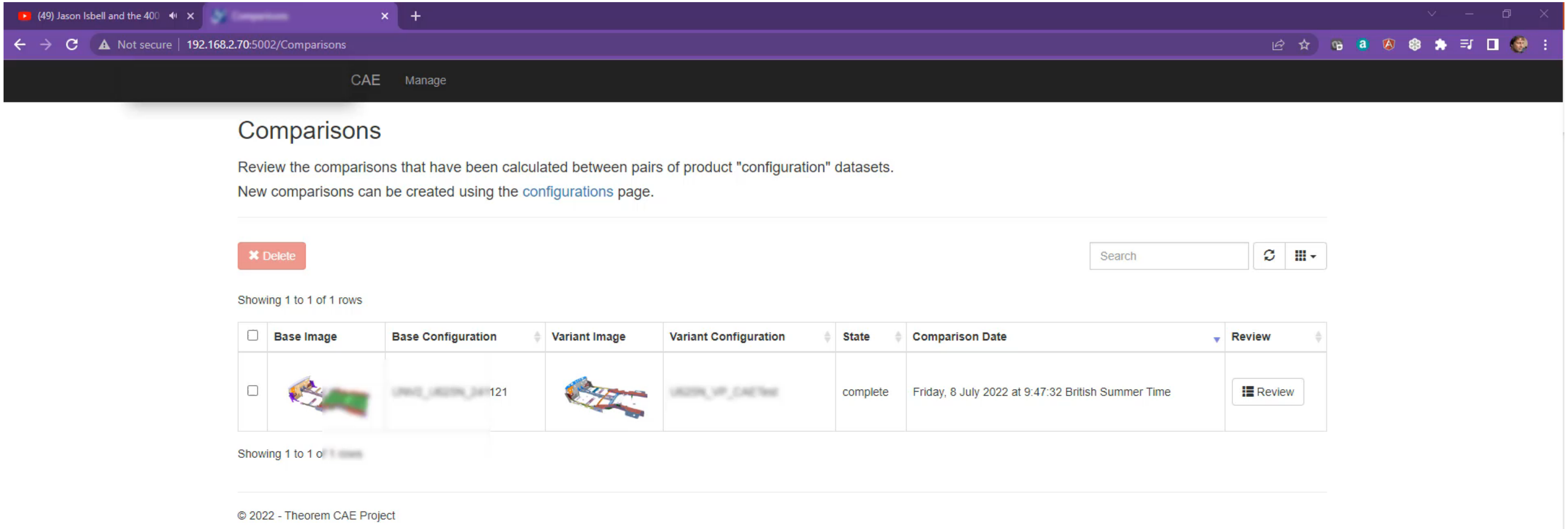
Solution

- Take a daily data feed from TeamCenter via PLMXML and JT files for each program
- Extract proprietary set of geometric features from each CAD file
- Feed into machine learning model trained on historic data linking part changes to subjective change score
- Filter and sort those parts with most significant changes
- Visualize geometry changes with custom web-based viewer

Deployment

- After a series of development phases, now live on around 10 North American programs
- Rolling out to all N. American programs this quarter
- Roll out to EMEA and APAC Q3 and Q4 2022

Problem 1: Identifying significant part changes



Problem 2: Intelligent Clash Management

Background

- During a vehicle design programme parts are checked out from PLM and checked back in at end of day
- Clash detection run over night providing report of all clashing parts
- Problem clashes should be fixed as soon as practical

Issues

- Current clash detect tool can take up to 24 hours to analyze a full vehicle
- Daily report rarely produced in a timely manner

Problem 2: Intelligent Clash Management

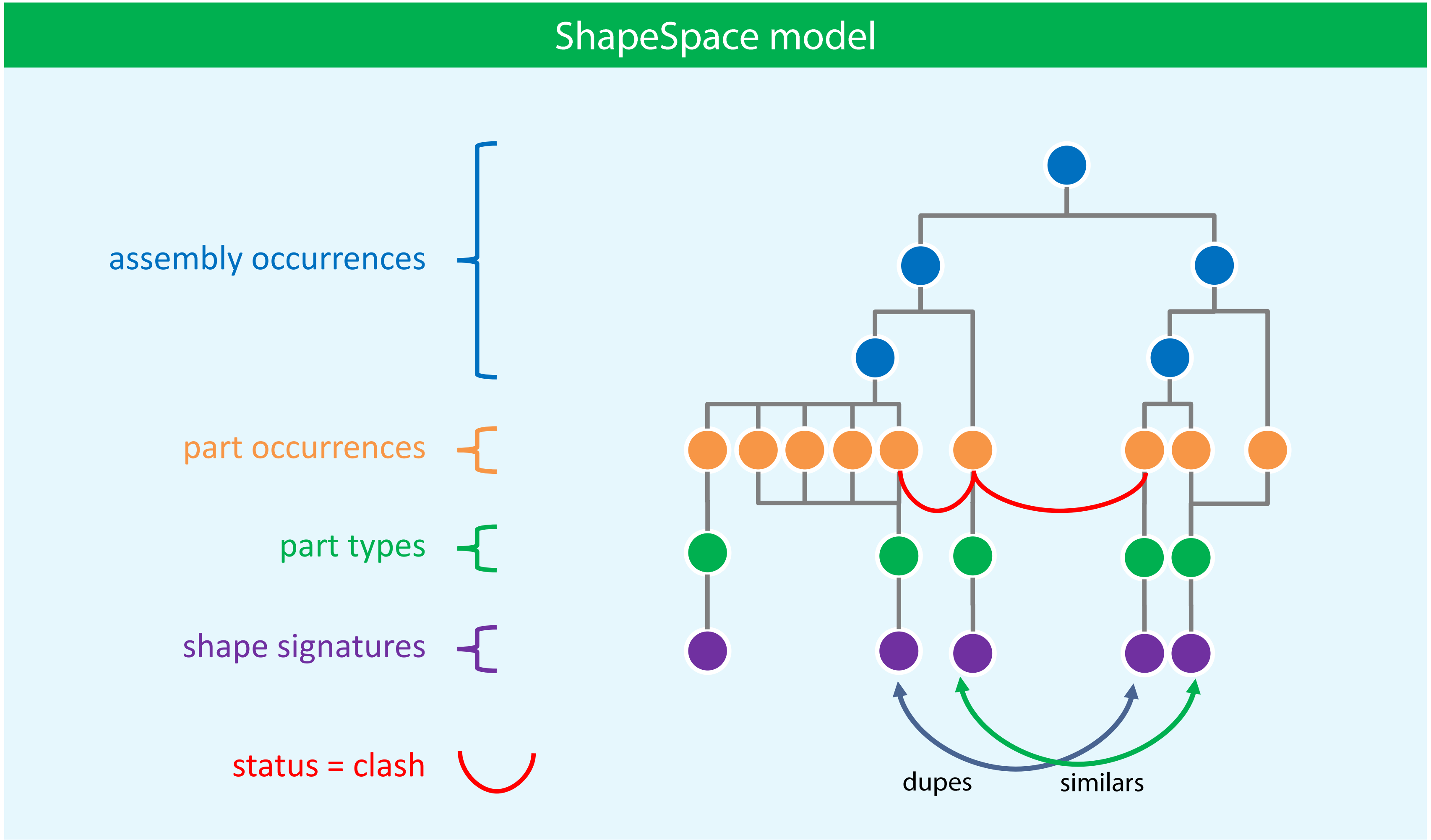
Solution

- Take a daily data feed from TeamCenter via PLMXML and JT files for each program
- Recognise that we are running clash detect everyday
- No need to check all potential clashes just those clashes where one or other component has changed position or geometry since yesterday
- Output vastly smaller set of potentially clashing component pairs for checking
- Reduction in run times from multiple hours to 10s of minutes.
- Provided as a microservice

Deployment

- After a series of development phases, now live on around 30 North American programs
- Rolling out to all N. American programs this quarter
- Roll out to EMEA and APAC Q3 and Q4 2022

OUR DATA STRUCTURE



OUR DATA STRUCTURE

ShapeSpace model

assembly occurrences

property	derived from
id	PLM XML rev id
transformation	PLM XML transformation
bounding box (?)	ShapeSpace calc from JT

part occurrences

property	derived from
id	PLM XML rev id
transformation	PLM XML transformation
bounding box (?)	ShapeSpace calc from JT

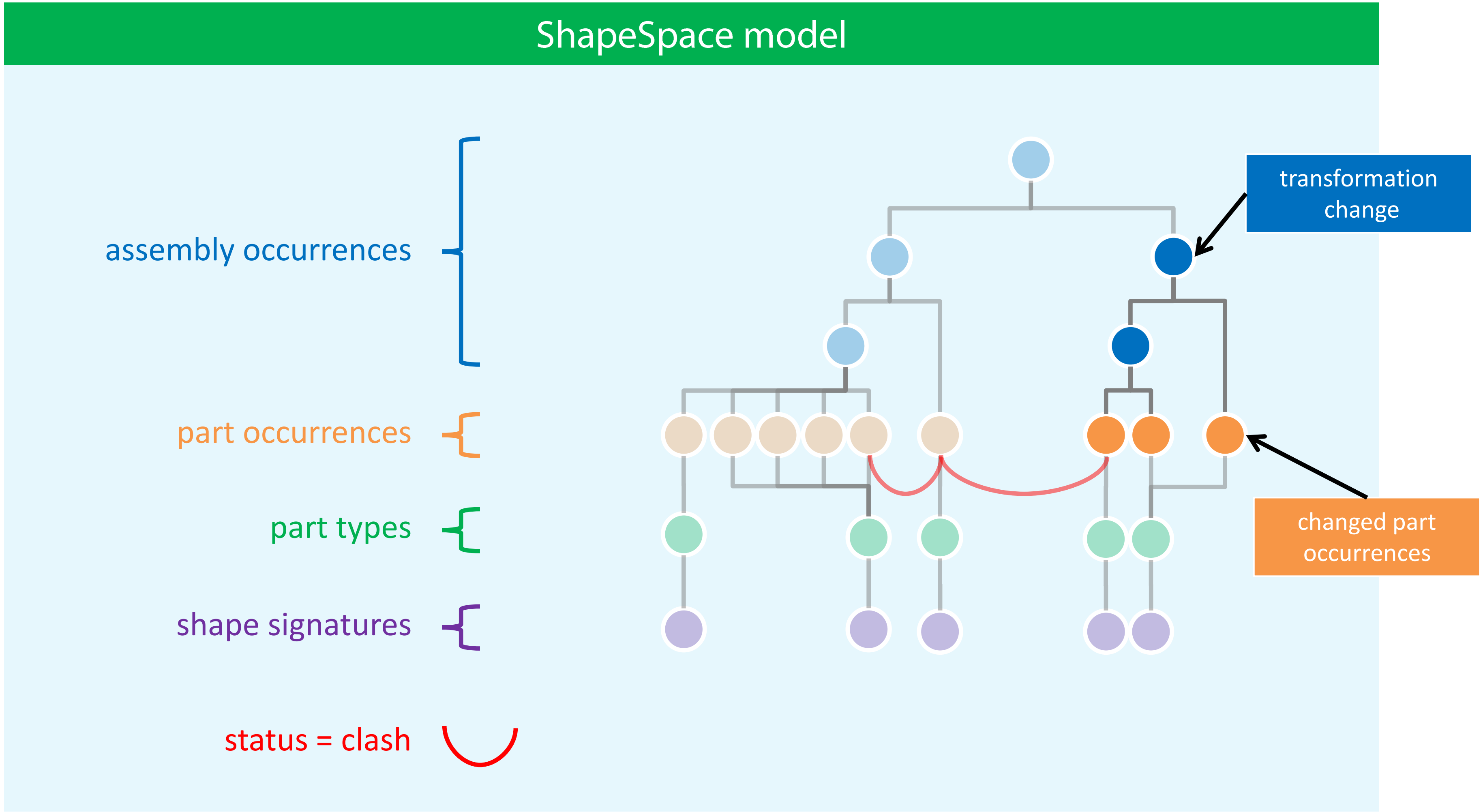
part types

property	derived from
id	PLM XML part rev id
JT reference	PLM XML reference

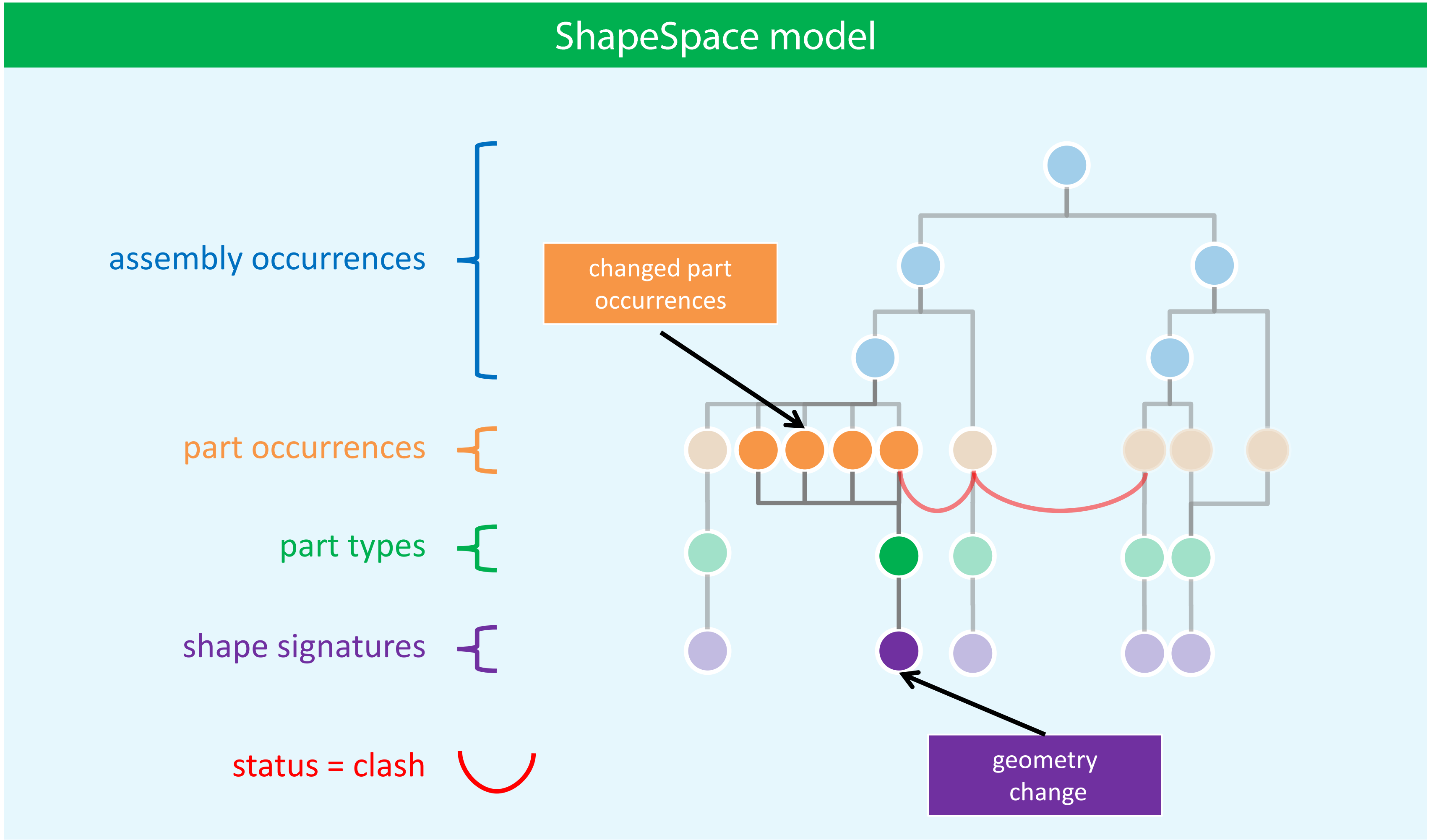
shape signatures

property	derived from
id	ShapeSpace derived
signature	ShapeSpace calc from JT (via STL)

Problem 2: Intelligent Clash Management



Problem 2: Intelligent Clash Management



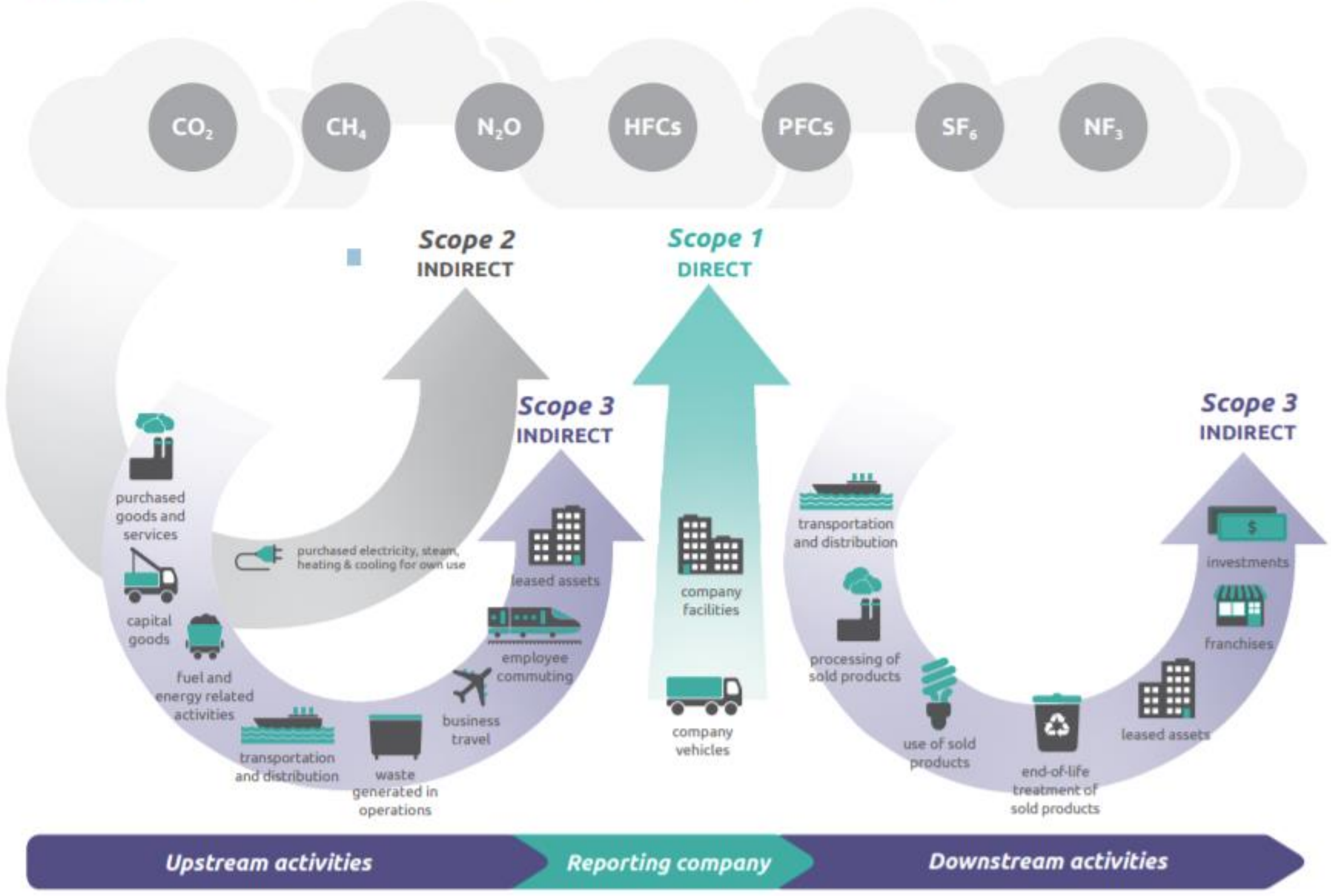
Carbon Accounting

Scope 1: Emissions which result from direct activities of your company.

Scope 2: Emissions which result from the generation of purchased electricity consumed by your company.

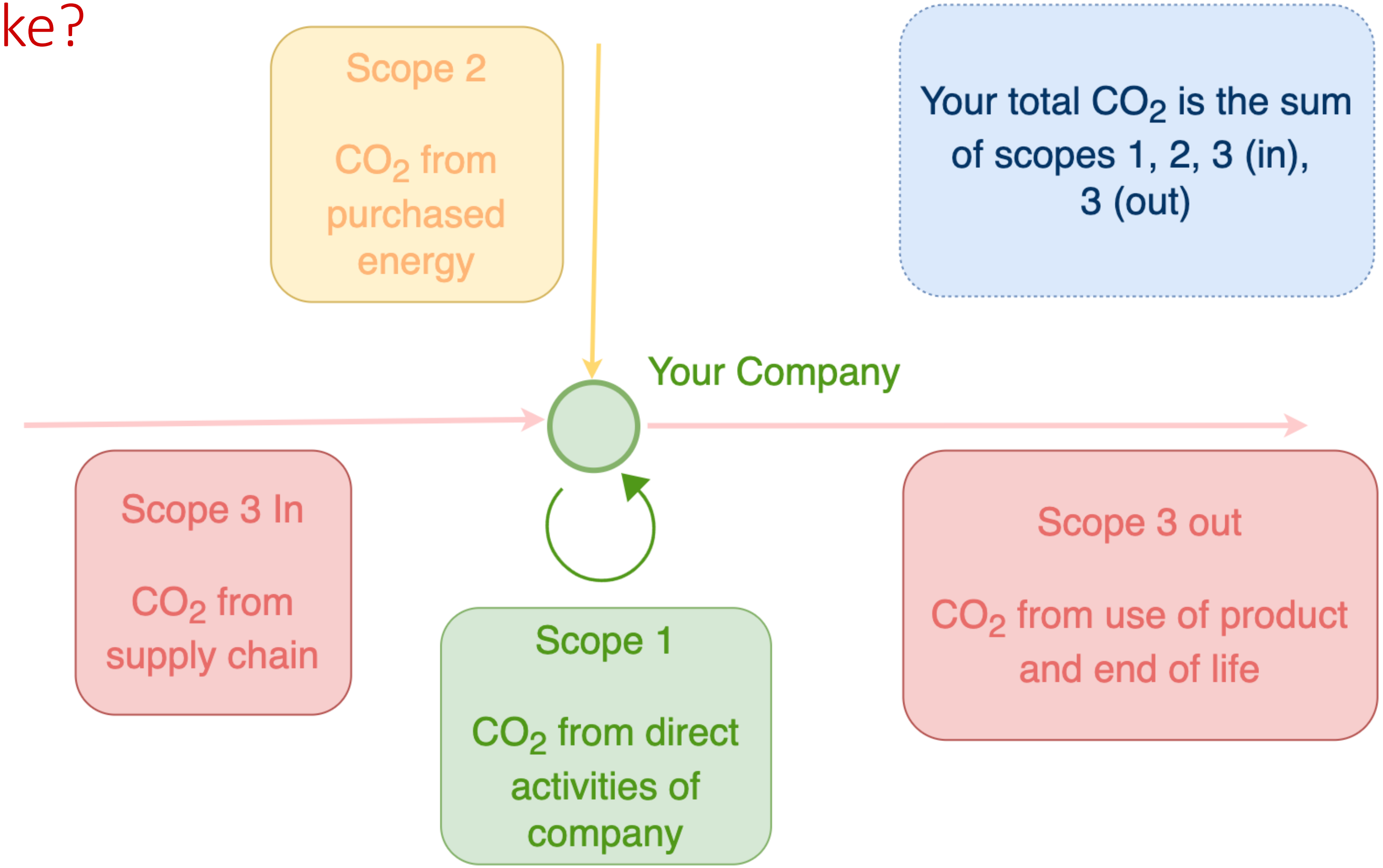
Scope 3: Emissions from all other indirect sources in your company's supply chain including all embedded carbon and end of life.

Figure [I] Overview of GHG Protocol scopes and emissions across the value chain

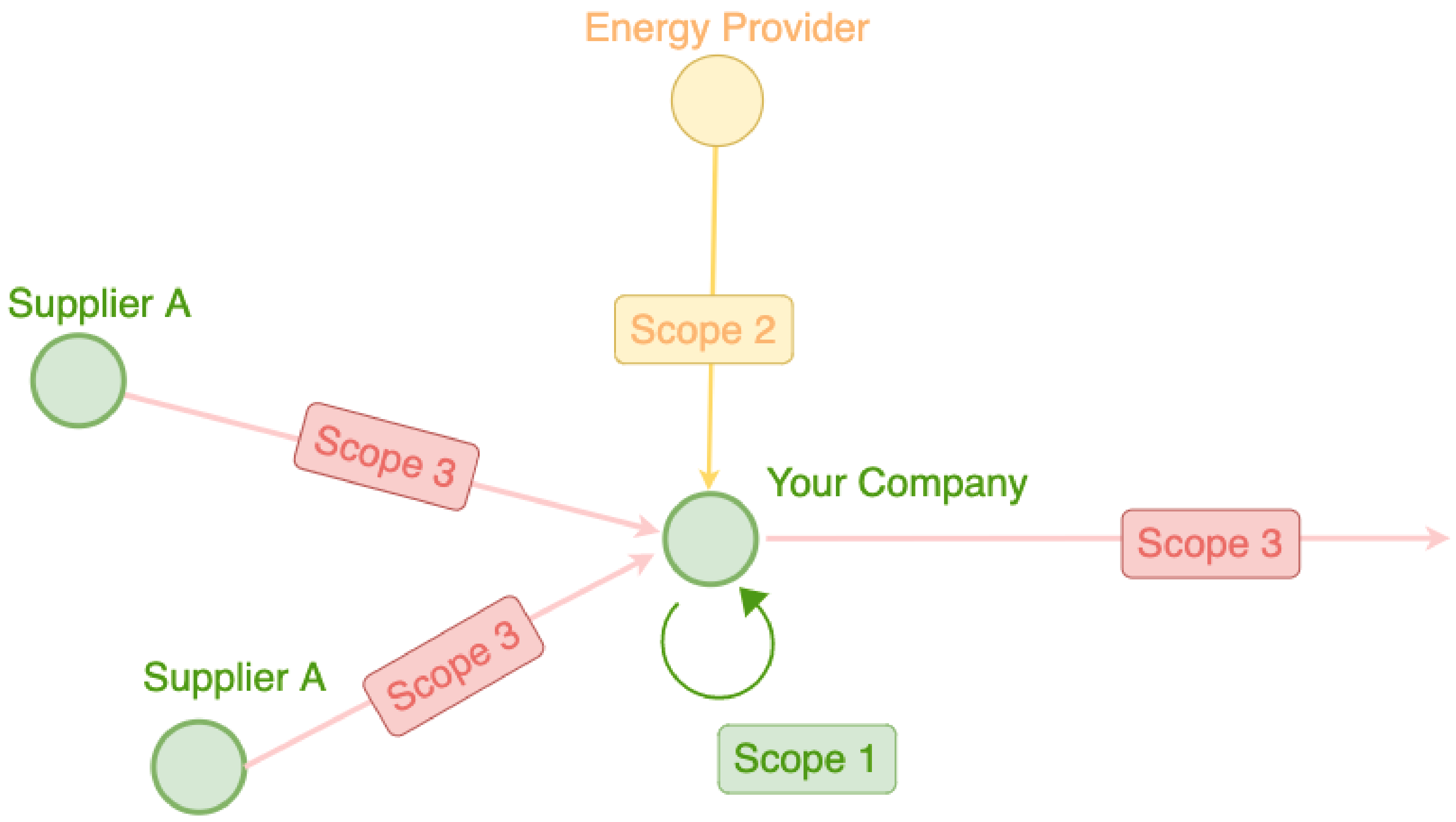


Source: Figure 1.1 of *Scope 3 Standard.*

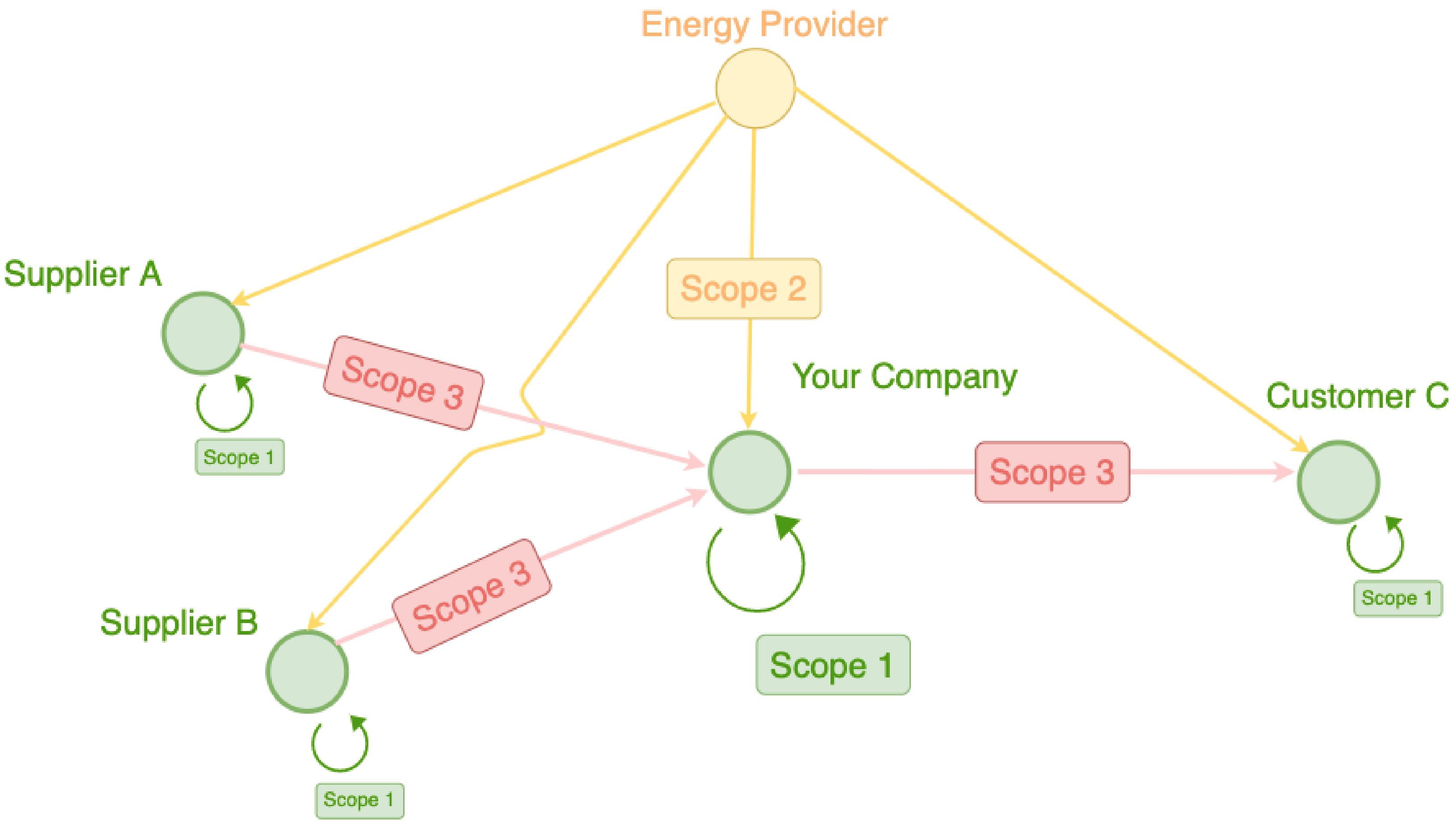
Carbon Accounting, what does this look like?



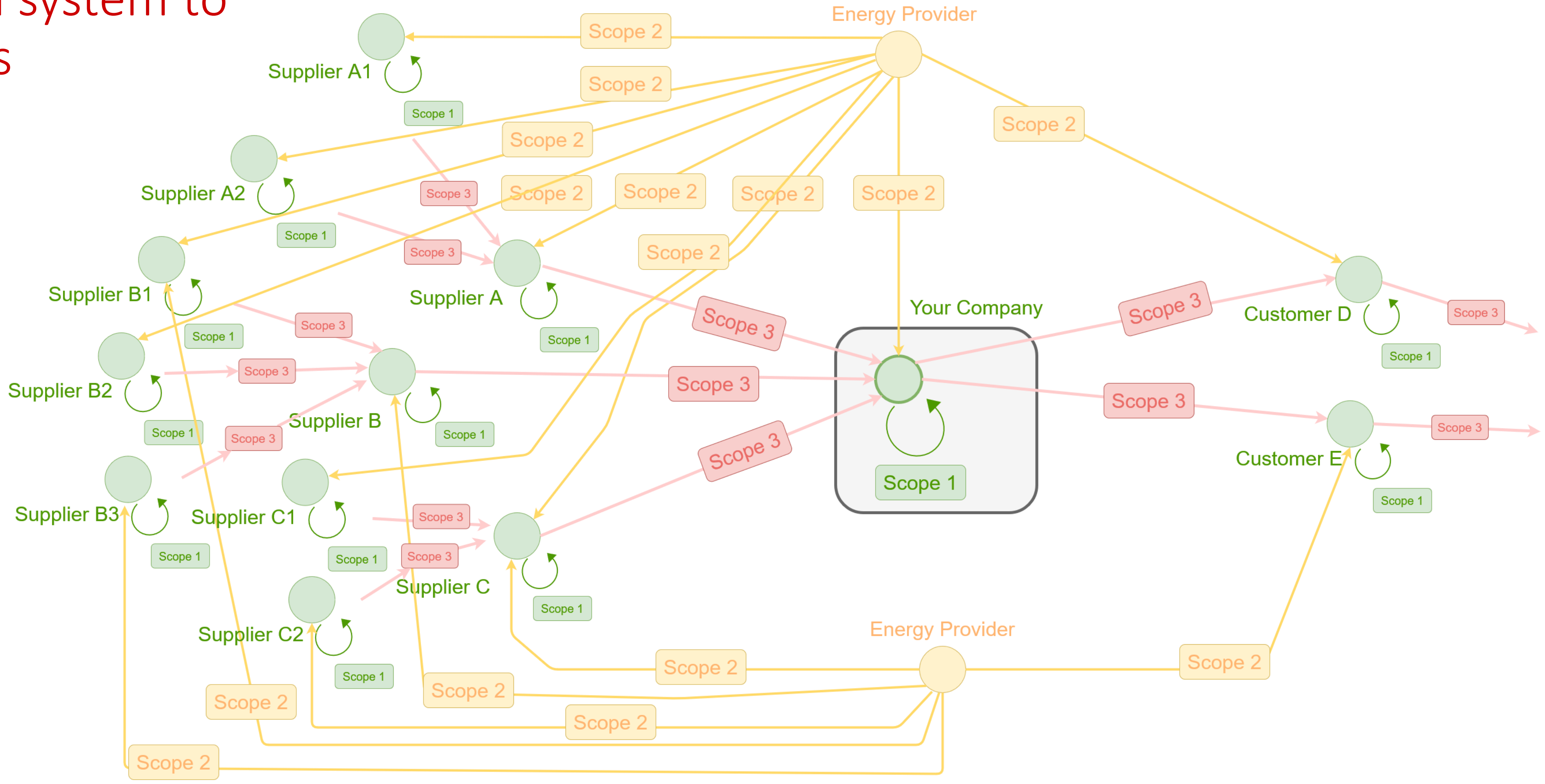
Scope 3 input emissions are totalled over all suppliers



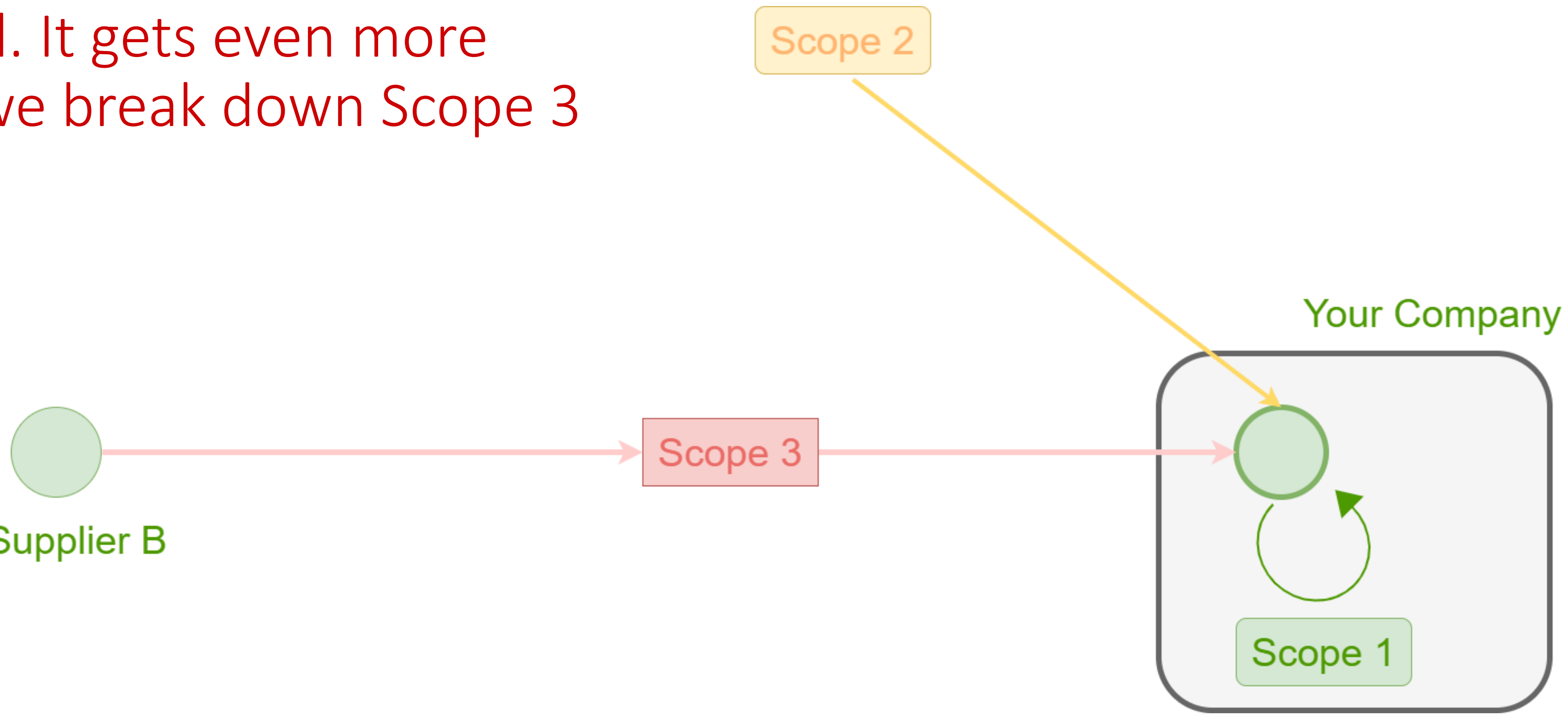
Starting to look complicated?



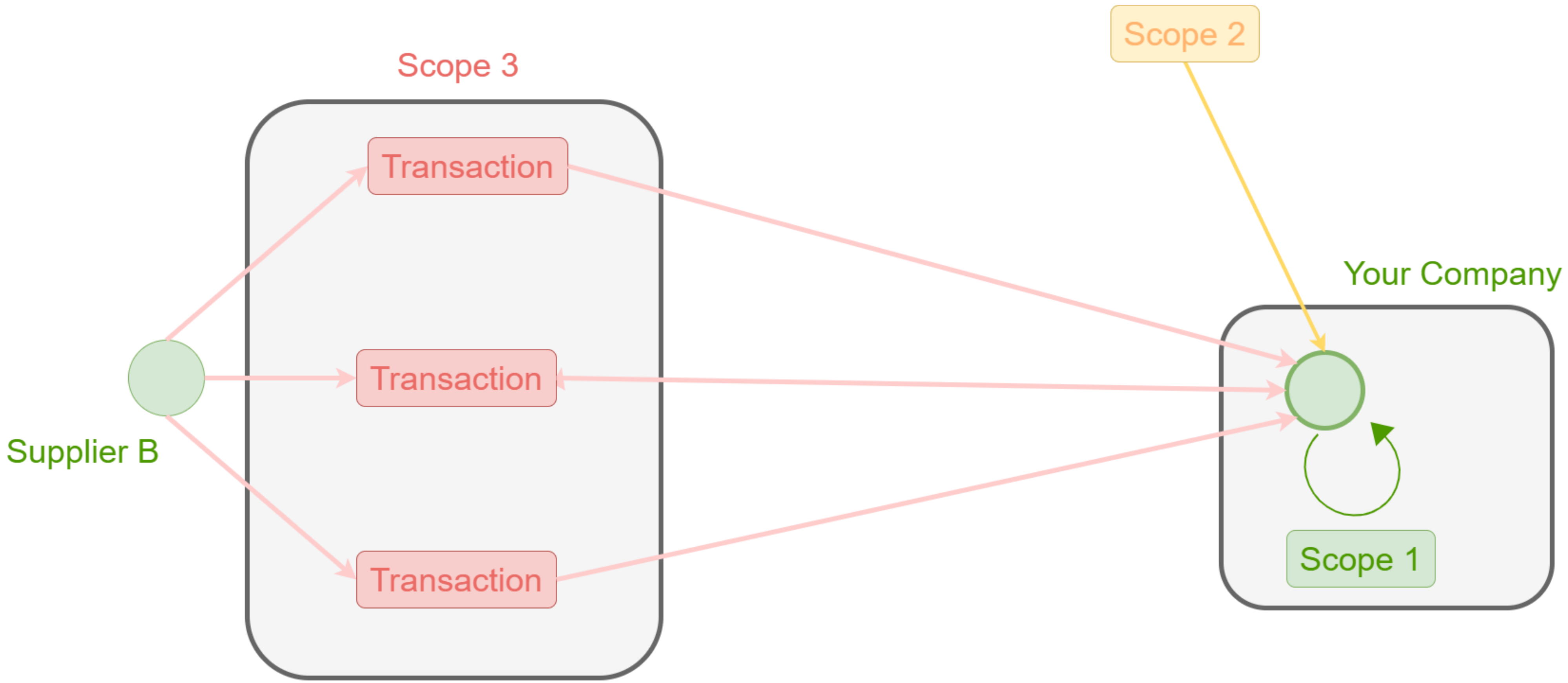
We need a system to handle this



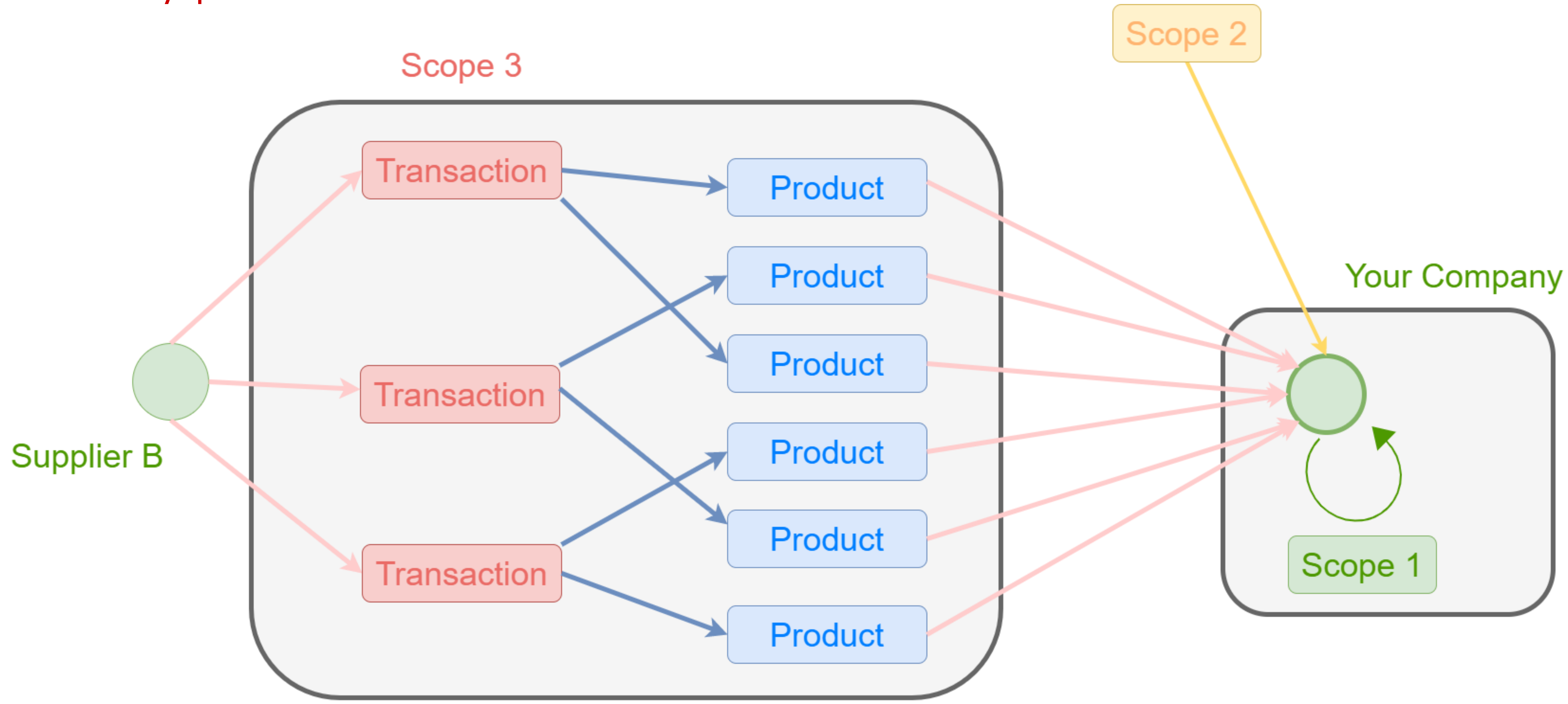
And that's not all. It gets even more complicated as we break down Scope 3



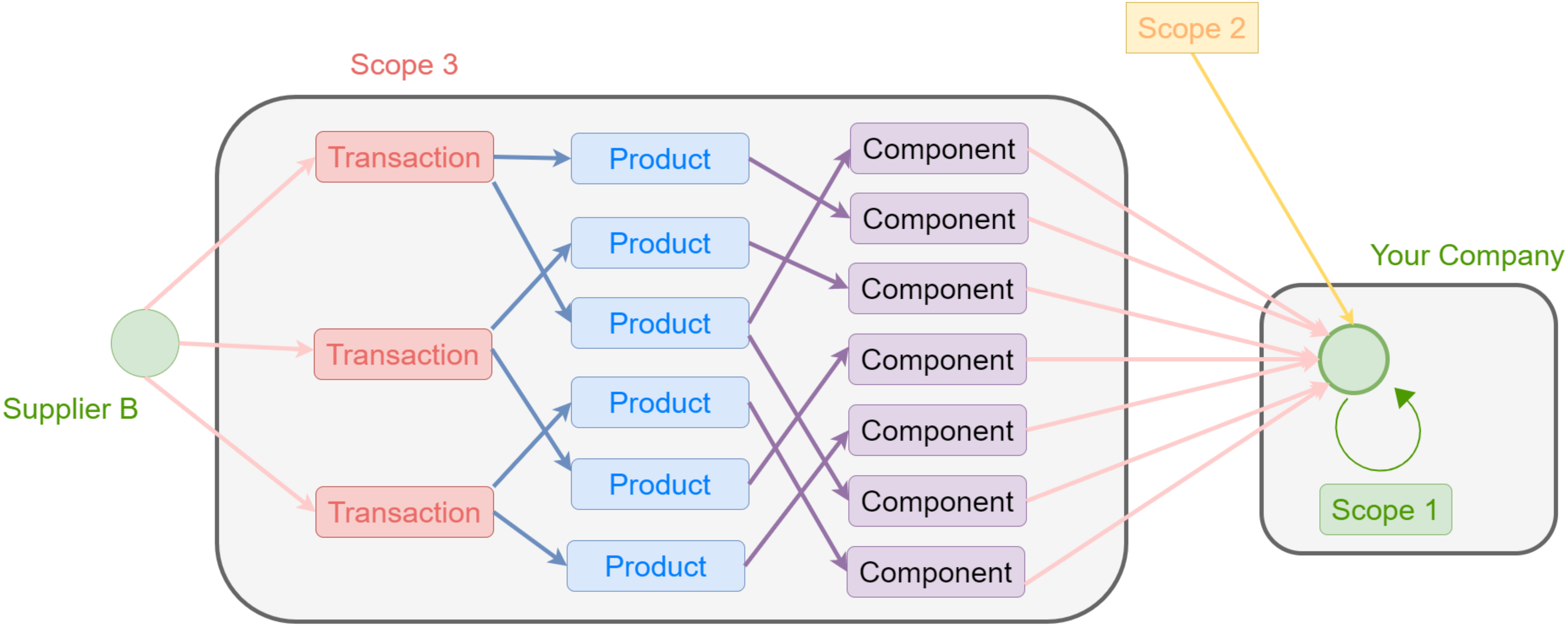
Allocate by transaction?



Allocate by product?



Allocate by component?



Aggregate solution:

- solve what we can,
- predict what we can't,
- handle uncertainty.

Data acquisition is expensive:

- Gather data where is makes most impact on our analysis