Design and Manufacturing Software for the Fab Lab Ecosystem

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Fab Academy
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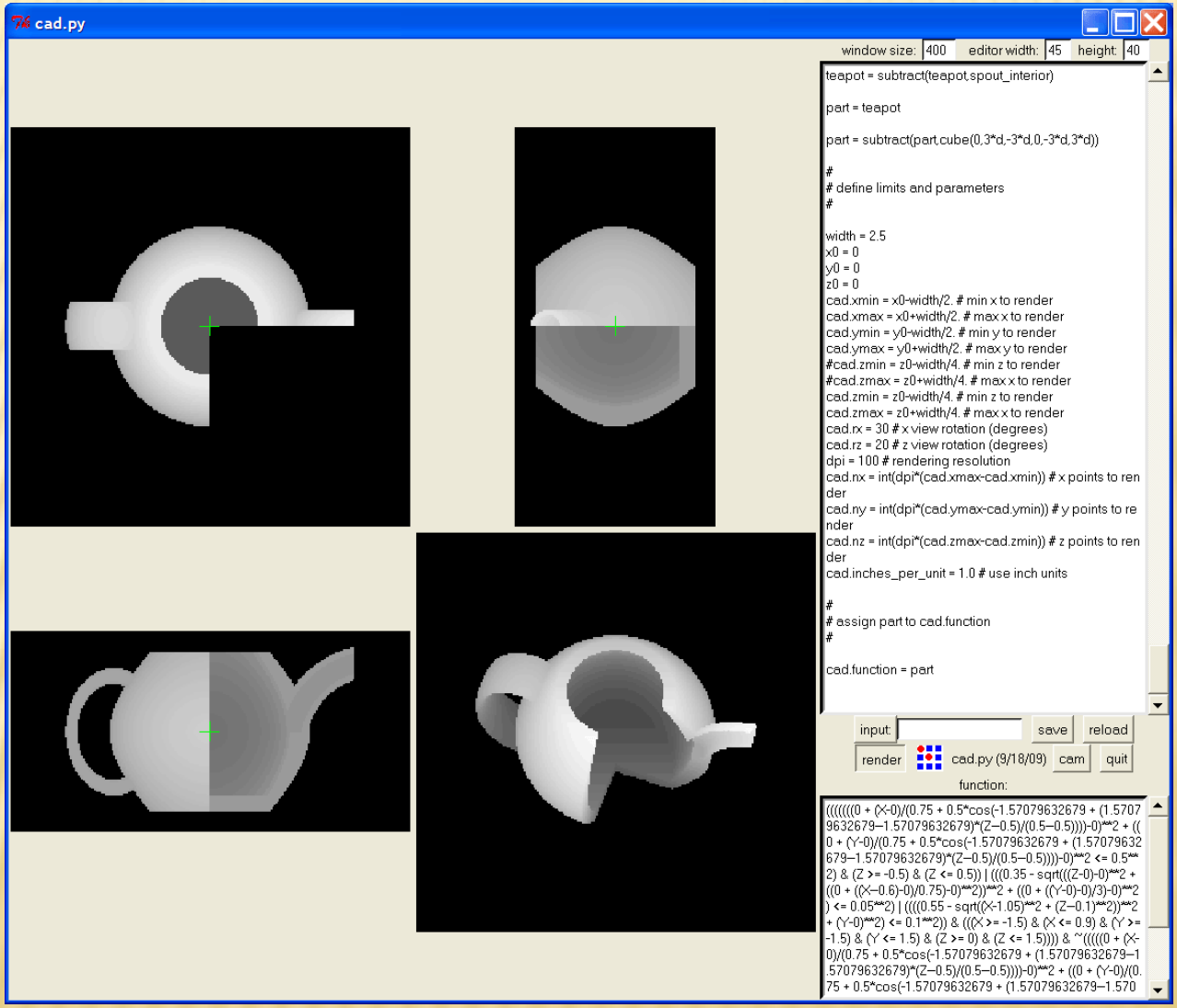
OUTLINE - OVERVIEW

- cad.py
- The next revision (Fab CAD/CAM)
  - Performance Optimizations
  - Front-end Improvements
  - Driving Machines

CAD.PY

- The math string – part of the *functional representation* family
- Defining geometry with python code
- Importing bitmaps
- Rendering
- Toolpath generation

CAD.PY


cad.py
window size: 400 editor width: 45 height: 40
teapot = subtract(teapot,spout_interior)
part = teapot
part = subtract(part,cube(0,3*d,-3*d,0,-3*d,3*d))
#
define limits and parameters
#
width = 2.5
x0 = 0
y0 = 0
z0 = 0
cad.xmin = x0-width/2. # min x to render
cad.xmax = x0+width/2. # max x to render
cad.ymin = y0-width/2. # min y to render
cad.ymax = y0+width/2. # max y to render
#cad.zmin = z0-width/4. # min z to render
#cad.zmax = z0+width/4. # max x to render
cad.zmin = z0-width/4. # min z to render
cad.zmax = z0+width/4. # max x to render
cad.rx = 30 # x view rotation (degrees)
cad.rz = 20 # z view rotation (degrees)
dpi = 100 # rendering resolution
cad.nx = int(dpi*(cad.xmax-cad.xmin)) # x points to ren
der
cad.ny = int(dpi*(cad.ymax-cad.ymin)) # y points to re
nder
cad.nz = int(dpi*(cad.zmax-cad.zmin)) # z points to ren
der
cad.inches_per_unit = 1.0 # use inch units
#
assign part to cad.function
#
cad.function = part
input:
save
reload
render
cad.py (9/18/09)
cam
quit
function:
(((((((0 + (X-0)/(0.75 + 0.5*cos(-1.57079632679 + (1.5707
9632679--1.57079632679)*(Z--0.5)/(0.5--0.5))))-0)**2 + ((
0 + (Y-0)/(0.75 + 0.5*cos(-1.57079632679 + (1.57079632
679--1.57079632679)*(Z--0.5)/(0.5--0.5))))-0)**2 <= 0.5**
2) & (Z >= -0.5) & (Z <= 0.5)) | (((0.35 - sqrt(((Z-0)-0)**2 +
((0 + ((X--0.6)-0)/0.75)-0)**2))**2 + ((0 + ((Y-0)-0)/3)-0)**2
) <= 0.05**2) | ((((0.55 - sqrt((X-1.05)**2 + (Z--0.1)**2))**2
+ (Y-0)**2) <= 0.1**2)) & (((X >= -1.5) & (X <= 0.9) & (Y >=
-1.5) & (Y <= 1.5) & (Z >= 0) & (Z <= 1.5)))) & ~((((((0 + (X-
0)/(0.75 + 0.5*cos(-1.57079632679 + (1.57079632679--1
.57079632679)*(Z--0.5)/(0.5--0.5))))-0)**2 + ((0 + (Y-0)/(0.
75 + 0.5*cos(-1.57079632679 + (1.57079632679--1.570

MATH STRING REPRESENTING A SQUARE

((X >= 0.5) & (X <= 1.5) &

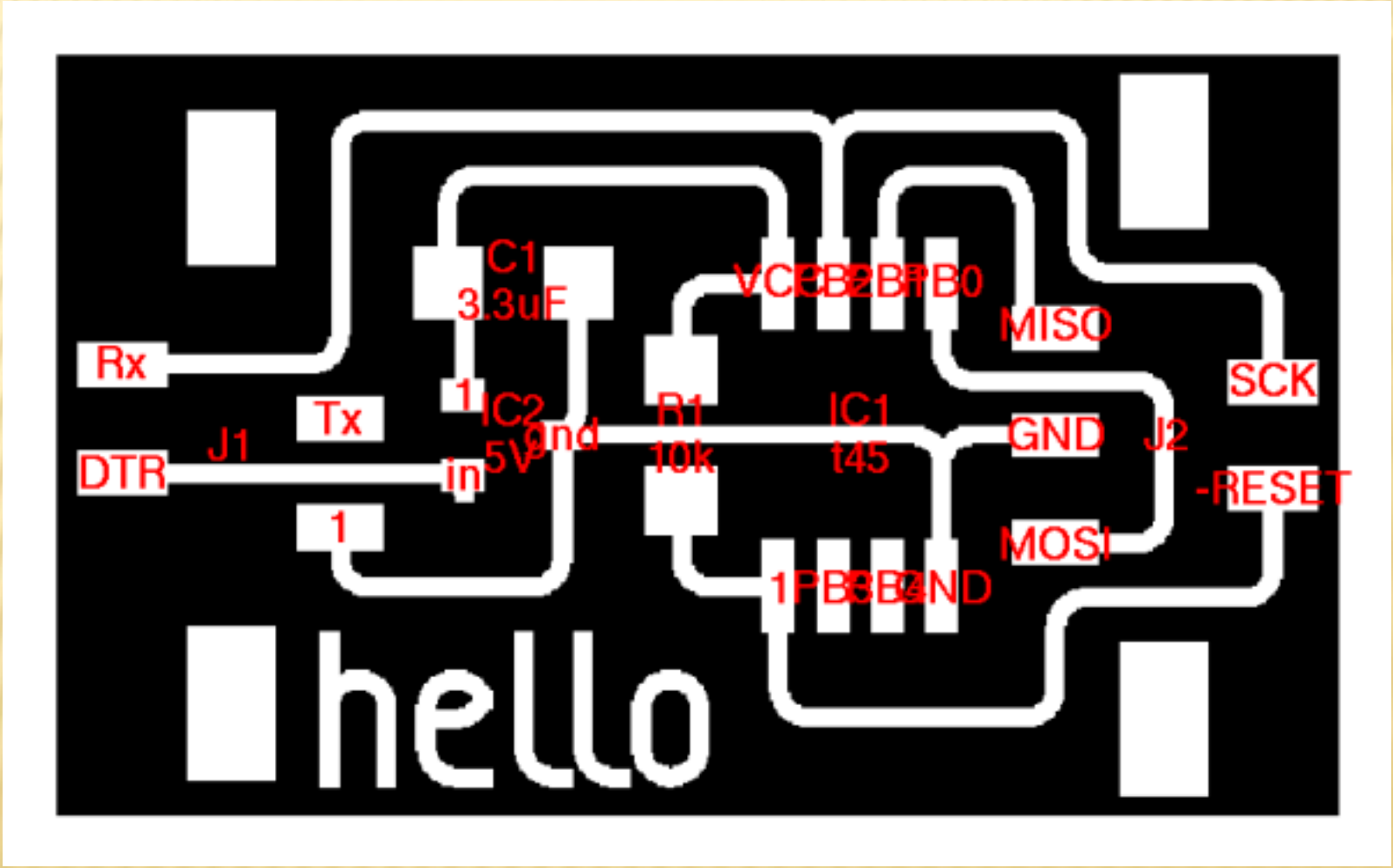
(Y >= 0.5) & (Y <= 1.5))

SLIGHTLY MORE COMPLEX…

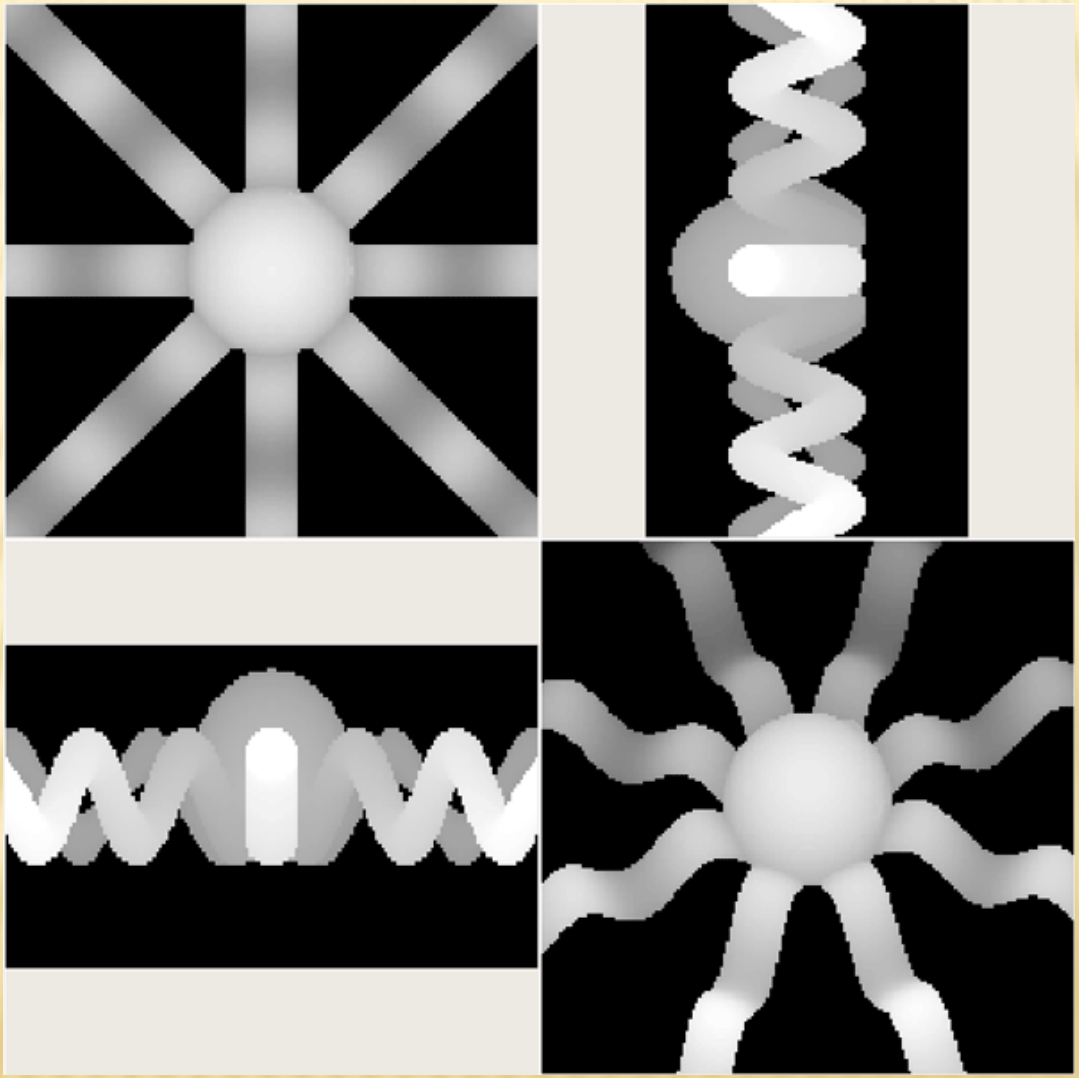
((X >= 0) & (X <= 5) & (Y >= 0) & (Y <= 32)) | ((X >= 9) & (X <= 14) & (Y >= 10) & (Y <= 32)) | ((X >= 18) & (X <= 23) & (Y >= 0) & (Y <= 32)) | ((X >= 27) & (X <= 32) & (Y >= 0) & (Y <= 23)) | ((X >= 27) & (X <= 32) & (Y >= 27) & (Y <= 32)) | ((X >= 36) & (X <= 41) & (Y >= 0) & (Y <= 23)) | ((X >= 36) & (X <= 54) & (Y >= 27) & (Y <= 32))

…WHICH REPRESENTS:

2D


C1
3.3uF
Rx
Tx
J1
DTR
IC2
5V
R1
10k
IC1
t45
MISO
SCK
GND
J2
-RESET
MOSI
hello

3D



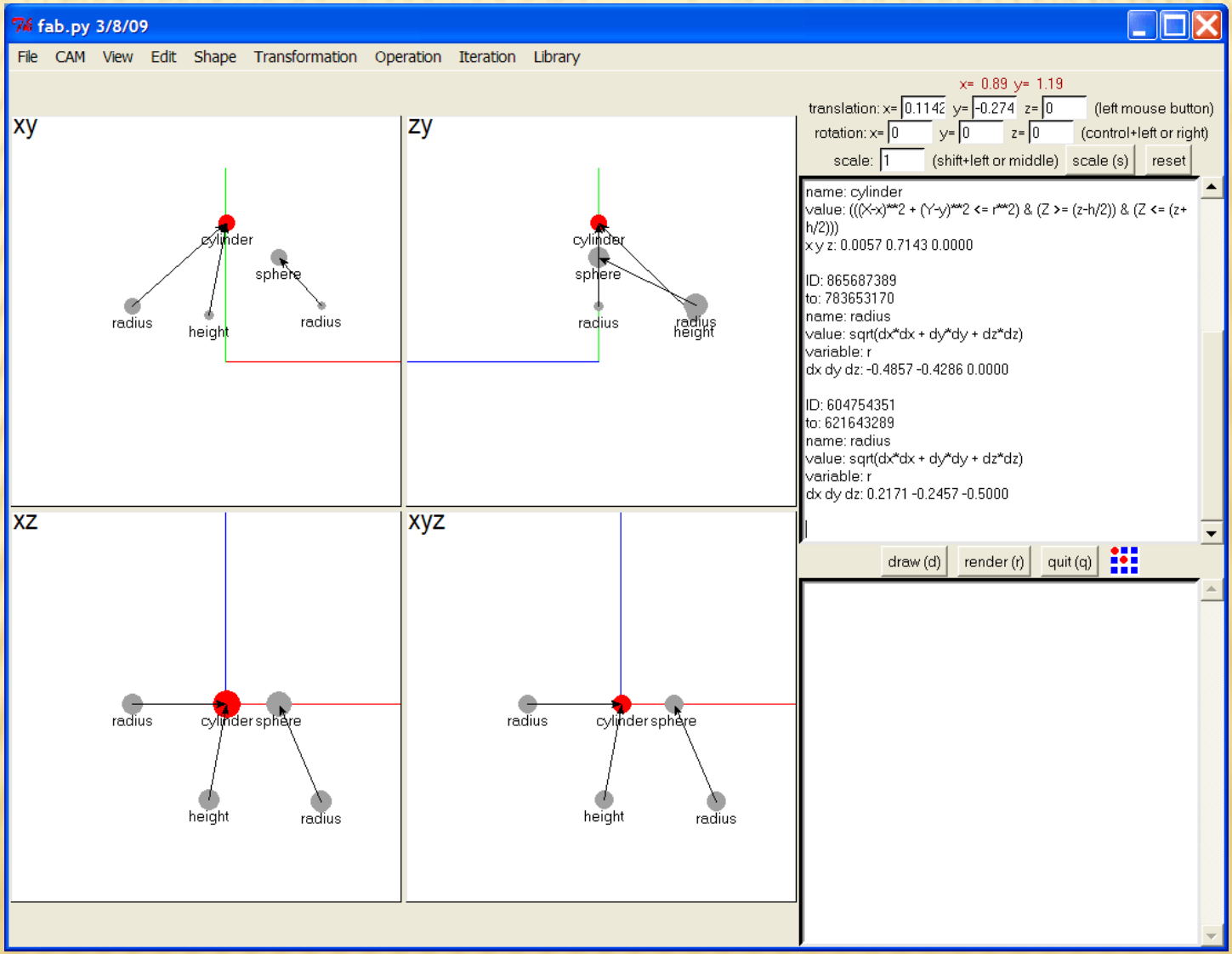
THE NEXT REVISION – FAB CAD/CAM

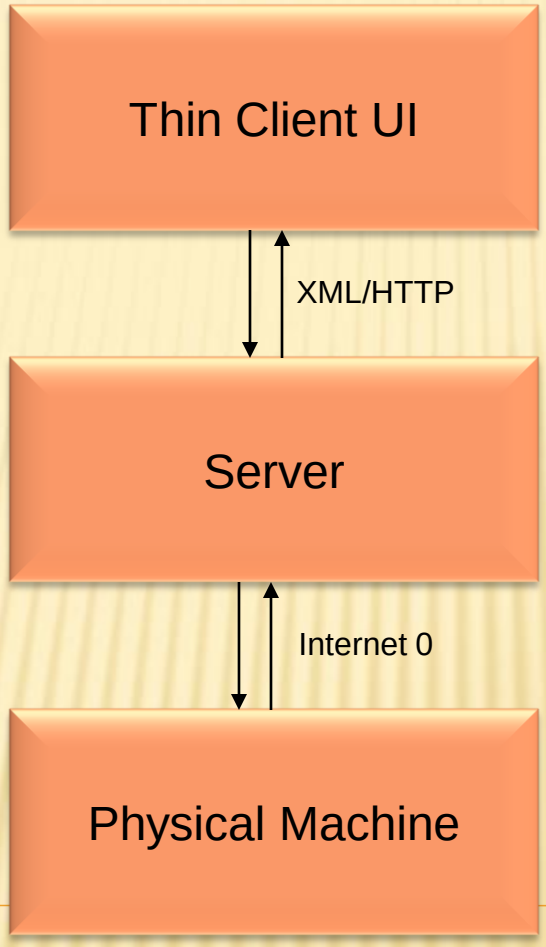
- Performance Optimizations
  - Octree
  - Interval arithmetic
- Front-end Improvements
  - Structure to encourage each adjective: hierarchical, parametric, procedural, algorithmic design
  - Visual Design
- Driving Machines
  - A programmatic geometry description
  - internet 0 as machine control protocol

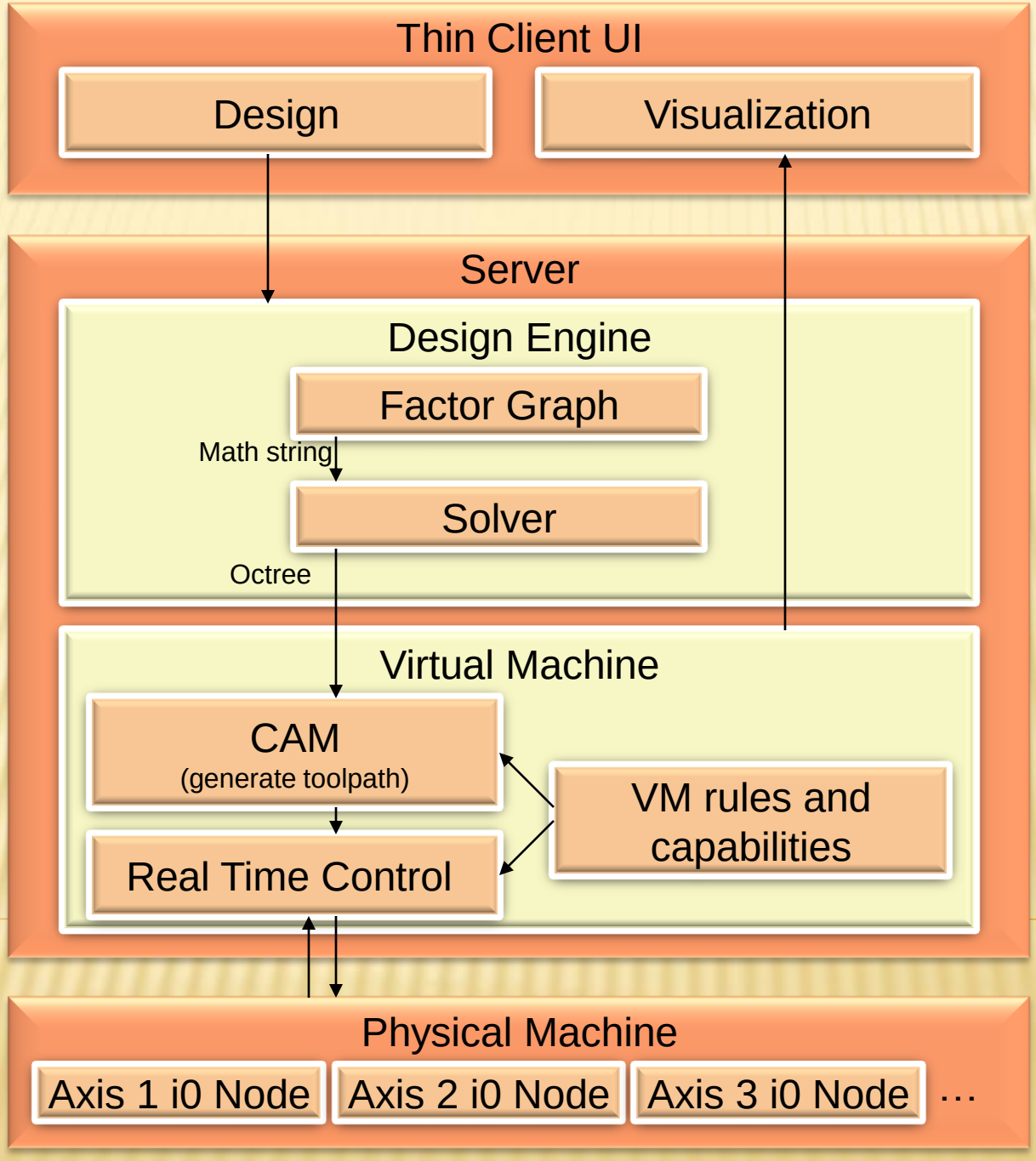
THE NEXT REVISION – FAB CAD/CAM

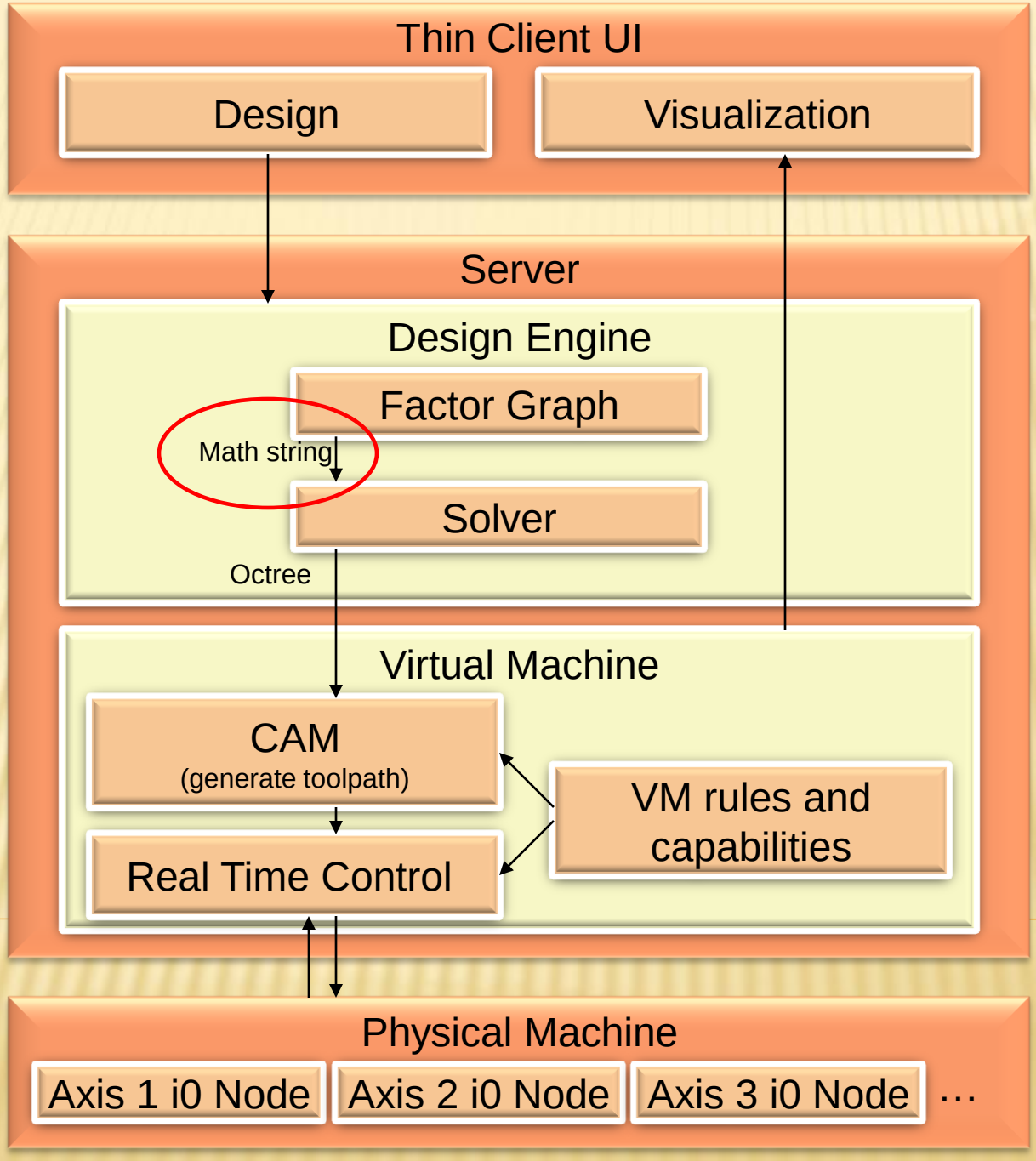
- Factor Graph GUI
  - Nodes represent parameters or objects
  - Connections can be used to override arbitrary information in the nodes
  - Physical location of the node is meaningful whenever it makes sense to use it
  - Example: A “sphere” node uses its location to represent the center of a physical sphere, and has a “radius” node connected to it. The “radius” node could also feed in as a parameter to other objects.

THE NEXT REVISION – FAB CAD/CAM




Thin Client UI
XML/HTTP
Server
Internet 0
Physical Machine


Thin Client UI
Design
Visualization
Server
Design Engine
Factor Graph
Math string
Solver
Octree
Virtual Machine
CAM
(generate toolpath)
Real Time Control
VM rules and capabilities
Physical Machine
Axis 1 i0 Node
Axis 2 i0 Node
Axis 3 i0 Node
…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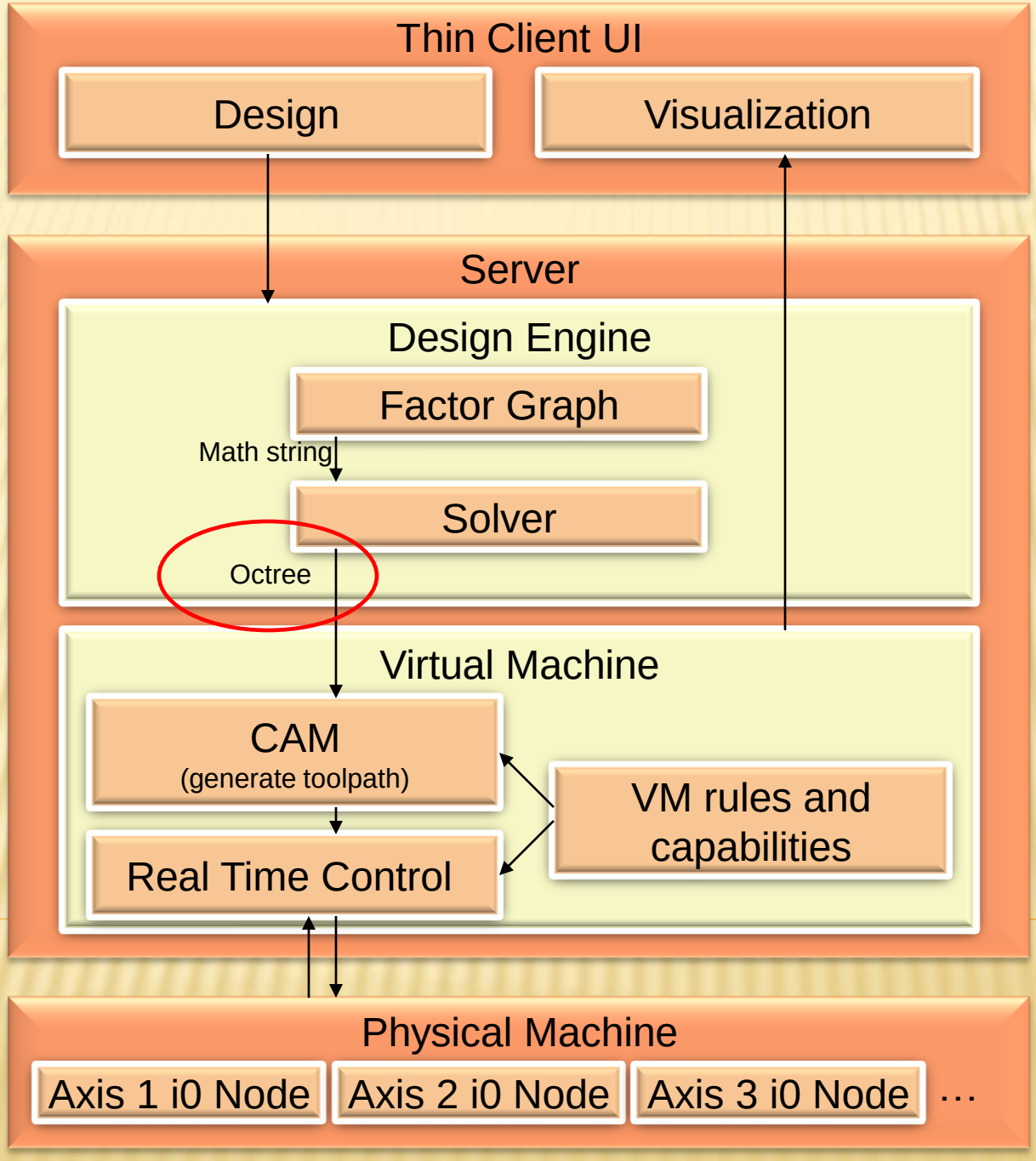
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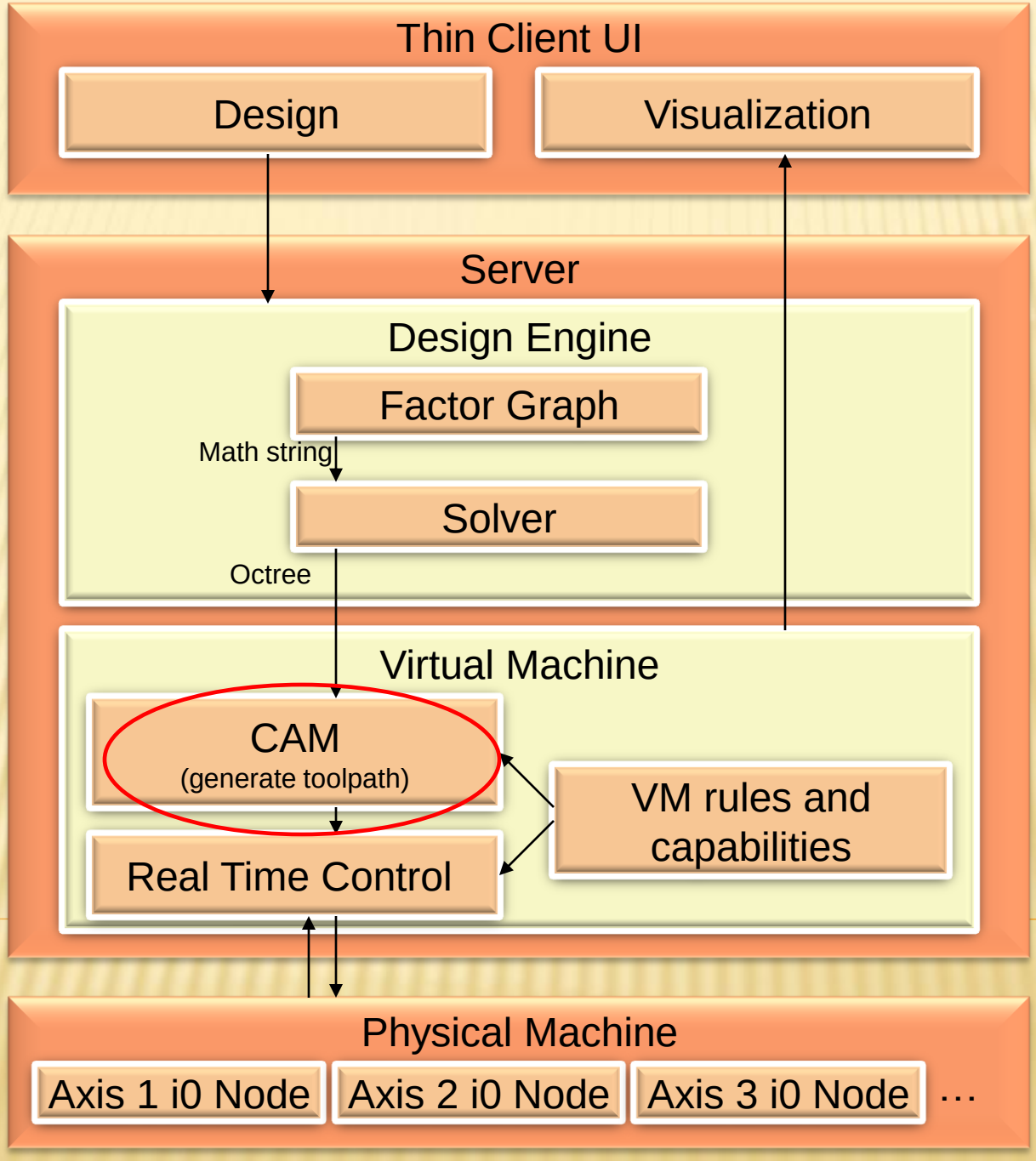
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TOO SLOW…

- Bearable for most practical 2D applications
- Hit the limit quickly for 3D objects

REVISIT THE MATH STRING FOR A SQUARE

((X >= 0.5) & (X <= 1.5) &

(Y >= 0.5) & (Y <= 1.5))

IMPROVEMENTS

- Don’t perform the evaluation everywhere
- Don’t evaluate the entire expression

OCTREE / QUADTREE

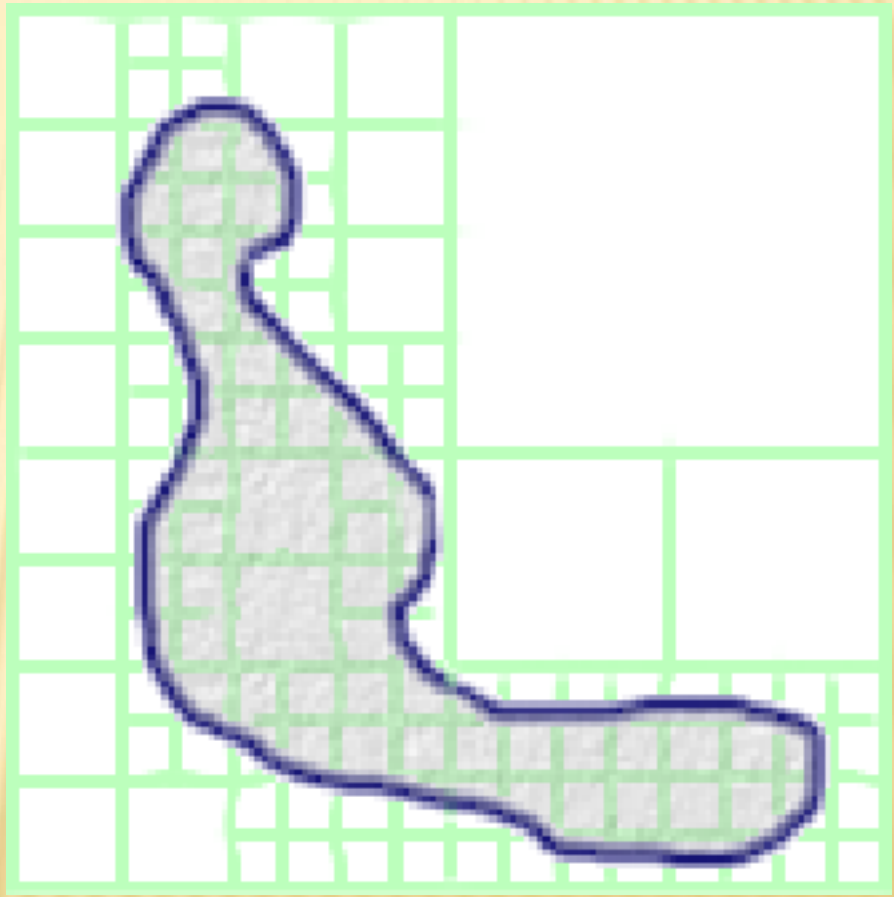
An object:

OCTREE / QUADTREE

Start chopping:

OCTREE / QUADTREE

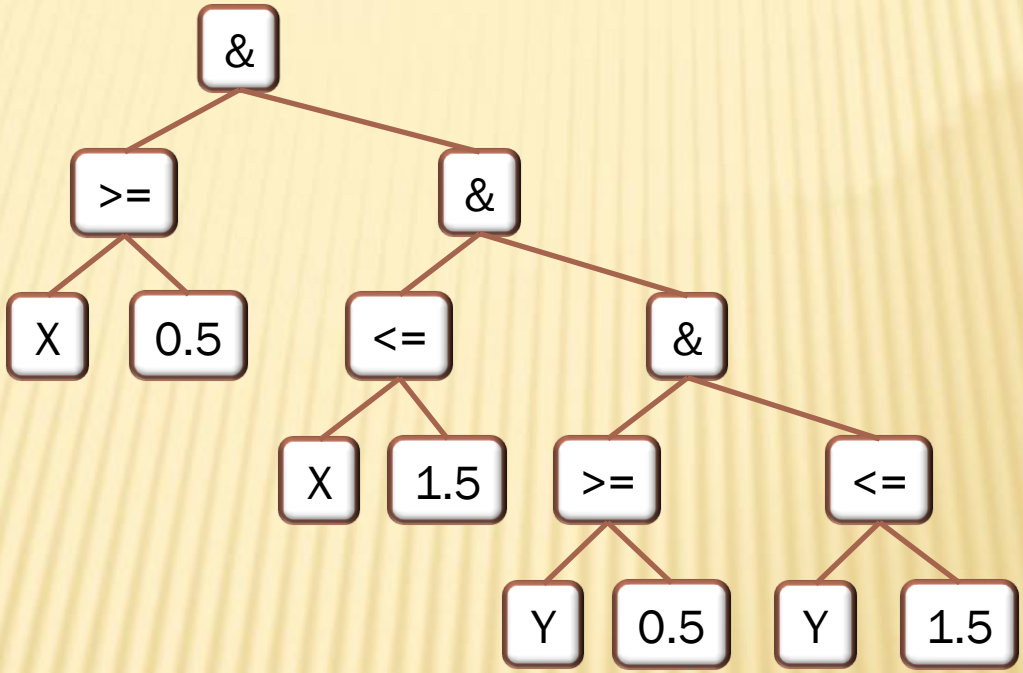
Recursively:



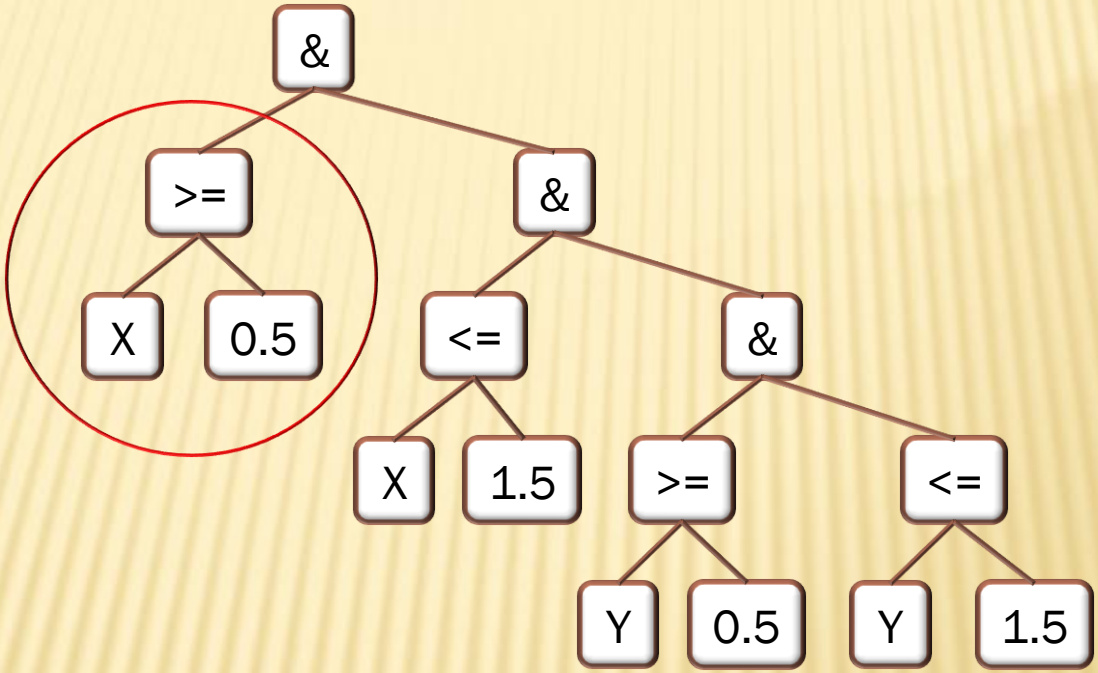
But without evaluating the math string everywhere, we don't yet know where the boundaries are…

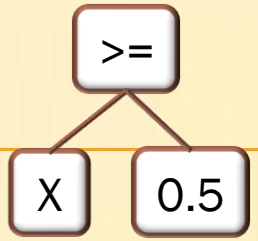
…remind me to answer that question 3 slides from now.

EXPRESSION TREE



EXPRESSION TREE





- Subregions that only contain space in the X>=0.5 portion of the plane do not need to be resolved any further.
- Subregions that span the X=0.5 line may (but are not guaranteed to) contain boundaries between solid material and empty space, so they do need to be resolved further.
- Subregions that only contain space in the X>0.5 portion of the plane may contain boundaries and need to be resolved further, but for these areas, the math string can be pruned to a shorter expression, eliminating the first condition.

RESULT

- Our quadtree/octree shows us large swaths of area that can be ignored
- We do not have to evaluate the entire math string anywhere. Significant chunks are pruned away

WHAT IF OUR SQUARE GETS A LITTLE CURVY?

((X >= sin(Y/(2*pi))) & (X <= 1.5) &

(Y >= 0.5) & (Y <= 1.5))

EXPRESSION INCLUDES A RANGE

((X >= some value in the range [-1,1]) & (X <= 1.5) & (Y >= 0.5) & (Y <= 1.5))

IMPLICATIONS

- Use interval arithmetic to deal with compound operations on ranges
- Slightly wider area in which the octree must be finely resolved

GENERATING TOOLPATHS

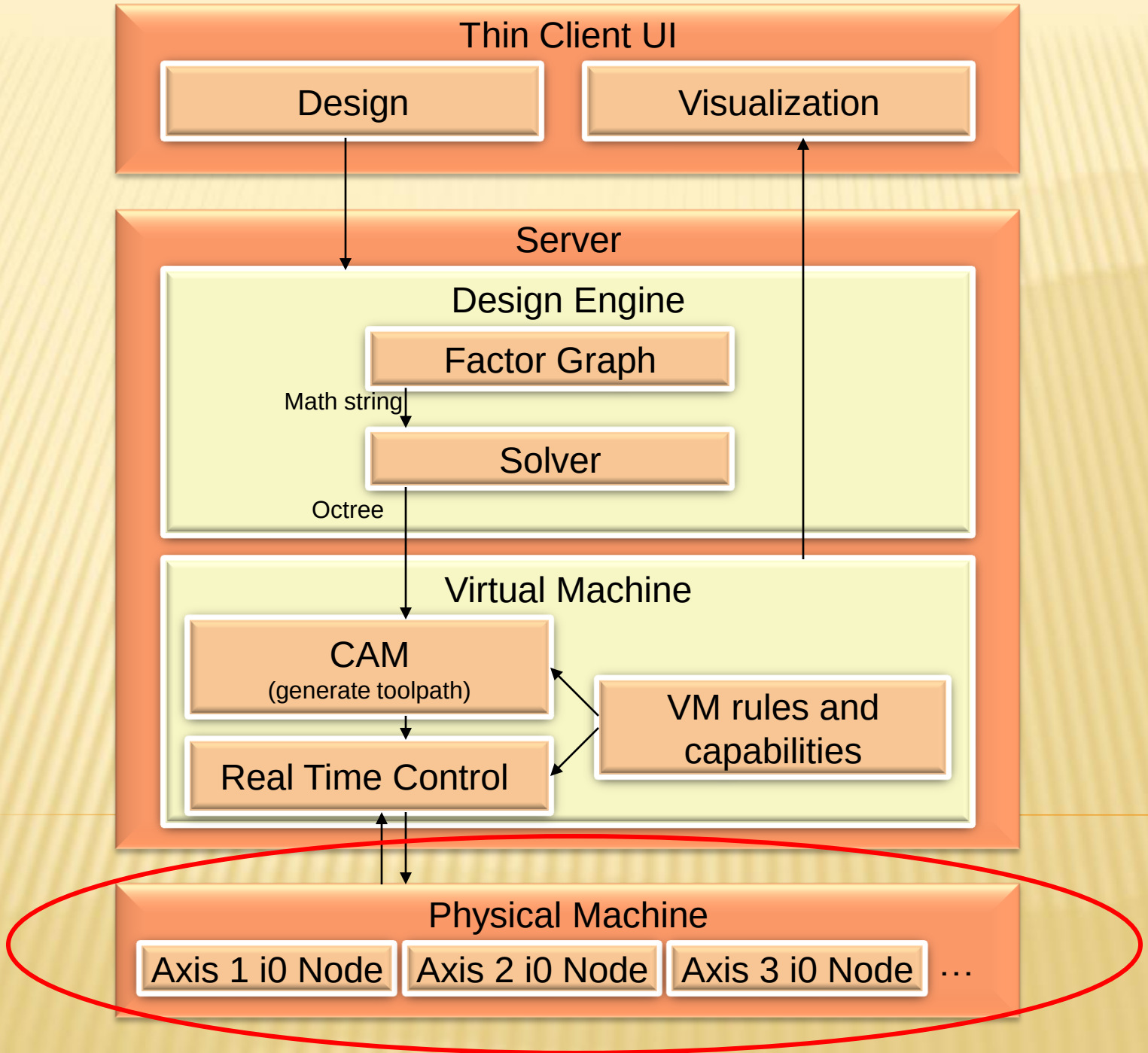
- Was easy when we had a fully resolved grid of values indicating True/False for the presence of material
- Do something analogous on the octree

GENERATING TOOLPATHS

- Evaluate (pruned) math string in octree leaf node region
- Compare with neighbors, identify boundaries
- Fully resolve to specified resolution along the boundary and where contours are requested
- Ignore everything else

TOOLPATH FORMAT (INSTRUCTIONS FOR THE VIRTUAL MACHINE)

```
traverse_speed = 8
cutting_speed = 4.0
plunge_speed = 4.0
z_down = 0.0
z_up = 0.1
move(z=z_up, rate=plunge_speed)
move(0.0, 0.0, z_up, traverse_speed)
move(z=z_down, rate=plunge_speed)
move(0.0462962963, 0.0, z_down, cutting_speed)
move(0.0462962963, 0.296296296, z_down,
    cutting_speed)
...
```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…and then the exciting part happens.

Things start getting built.