Geometry and Physics Modeling with Python

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Outline

Motivations for a new entry

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The easiest solution?

Pyplasm: Plasm → Python

PLaSM (Programming Language for Solid Modeling)

Geometric extension of Backus' FL (IBM Yorktown)

(Multidimensional) Geometric Programming at Function Level

- Points, curves, surfaces, solids and higher-dim manifolds

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  - d-Skeletons, $0 \leq d \leq n$
  - Convex hulls
  - Domain integrals of polynomials

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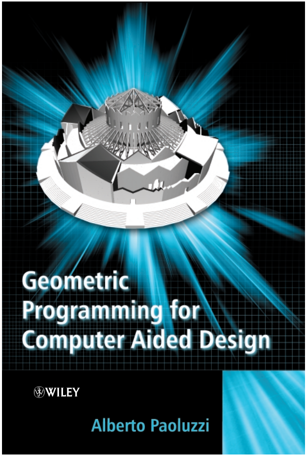
Documentation

Paoluzzi, A., Pascucci, V. & Vicentino, M. (1995). Geometric programming: a programming approach to geometric design. *ACM Trans. Graph.* **14** (3), 266–306.



Three general rules to write pyplasm code

Plasm primitives

ALL CAPS	all capital letters

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Application

is always unary — VIEW(CUBOID([1,4,9]))

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Higher-level functions

Unusual but legal in Python COLOR(RED)(CUBE(1))

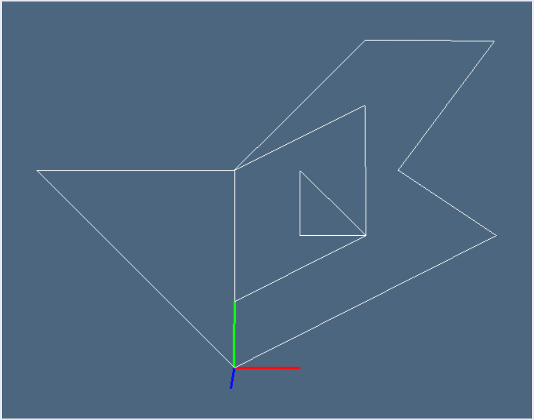
Boolean ops example: polygon filling

```
List = [
[[0,0],[4,2],[2.5,3],
 [4,5],[2,5],[0,3],
 [-3,3],[0,0]],

[[0,3],[0,1],[2,2],
 [2,4],[0,3]],

[[2,2],[1,3],[1,2],
 [2,2]]
]
```

polylines = STRUCT(AA(POLYLINE)(List))



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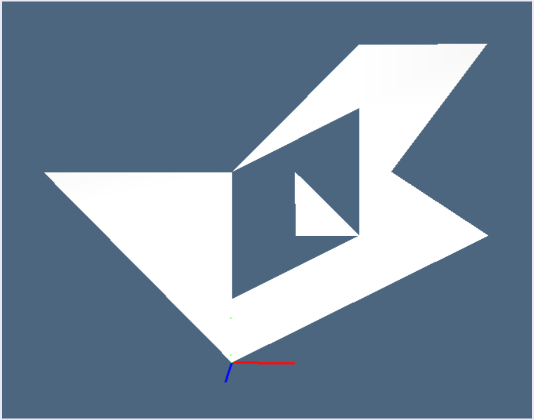
```

polygon = SOLIDIFY(polylines)



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```
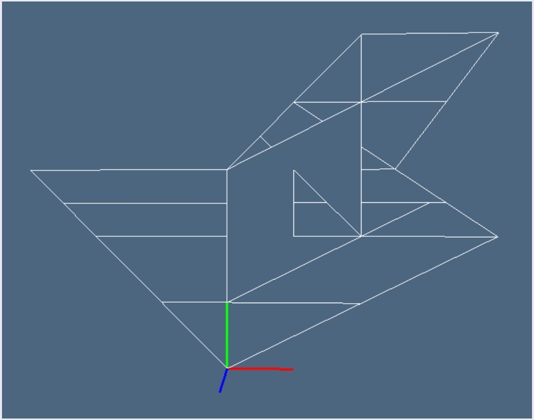

cells = SKELETON(1)(polygon)



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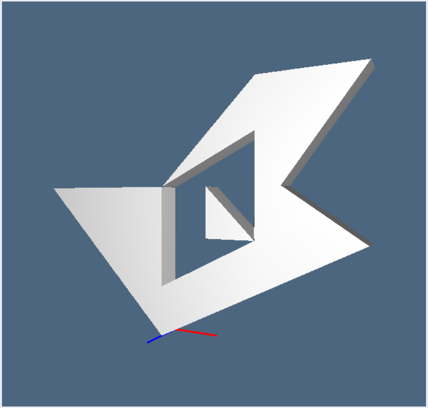
```

solid = PROD([polygon, Q(0.5)])



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[[2,2],[1,3],[1,2],
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]
```
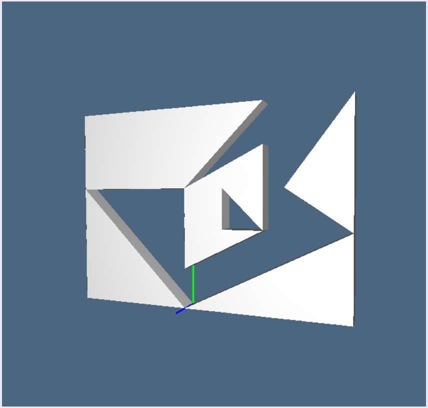

complement = DIFFERENCE([
BOX([1,2,3])(solid), solid])



Coding a new pyplasm primitive

```
from pyplasm import *

def EXPLODE (params):
    sx,sy,sz = params
    def explode0 (scene):
        centers = AA(MED([1,2,3]))(scene)
        scalings = N(len(centers))(S([1,2,3])([sx,sy,sz]))
        scaledCenters = AA(UK)(AA(APPLY)(TRANS([scalings,AA(MK)(centers)])))
        translVectors = AA(VECTDIFF)(TRANS([scaledCenters, centers]))
        translations = AA(T([1,2,3]))(translVectors)
        return STRUCT(AA(APPLY)(TRANS([translations, scene])))
    return explode0
```

The pyplasm EXPL in plain python

```
from pyplasm import *

def EXPLODE (dims):
    dims = [dims] if ISNUM(dims) else dims
    def EXPLODE0 (params):
        params = [params] if ISNUM(params) else params
        def EXPLODE1 (scene):
            centers = [MED(INTSTO(RN(obj)))(obj) for obj in scene]
            scalings = len(centers) * [S(dims)(params)]
            scaledCenters = [UK(APPLY(pair)) for pair in
                zip(scalings, [MK(p) for p in centers])]
            translVectors = [ VECTDIFF((p,q)) for (p,q) in zip(scaledCenters, centers) ]
            translations = [ T(dims)(v) for v in translVectors ]
            return STRUCT([ APPLY([t,obj]) for t,obj in zip(translations,scene) ])
        return EXPLODE1
    return EXPLODE0

EXPL = EXPLODE
```

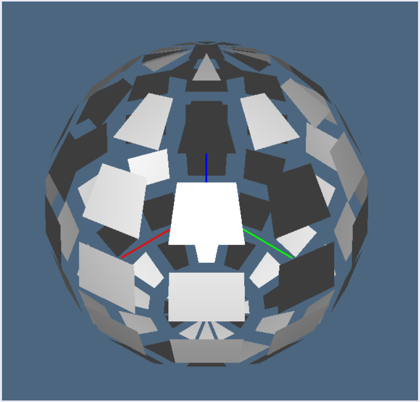
EXPL examples

List = SPLITCELLS(SPHERE(1)([8,12]))

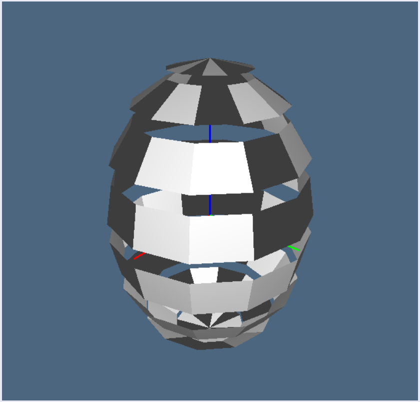
EXPL examples

List = SPLITCELLS(SPHERE(1)([8,12]))

pol1=EXPL([1,2,3])([1.5,1.5,1.5])(List)



pol2 = EXPL(3)(1.5)(List)



Minkowsky sum of cell complexes with a convex cell

polList1 = SPLITCELLS(SK(1)(pol1))

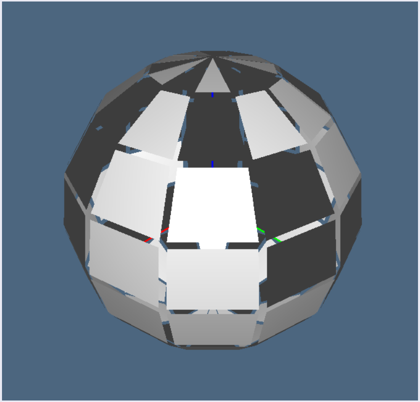
polList2 = SPLITCELLS(pol1)

Minkowsky sum of cell complexes with a convex cell

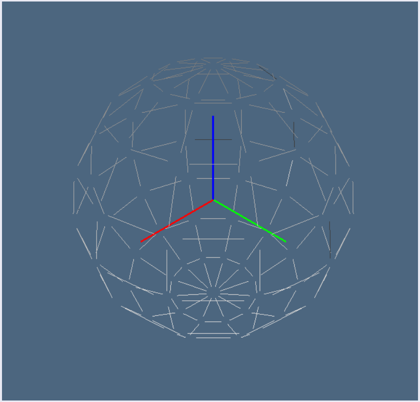
polList1 = SPLITCELLS(SK(1)(pol1))

polList2 = SPLITCELLS(pol1)

EXPL([1.5,1.5,1.5])(polList1))



EXPL([1.5,1.5,1.5])(polList2)



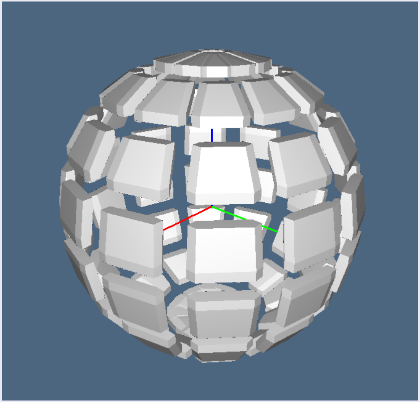
Minkowsky sum of cell complexes with a convex cell

def fun (poly): return COMP([EXPL([1.5,1.5,1.5]), SPLITCELLS, (OFFSET([.1,.1,.1])])(poly)

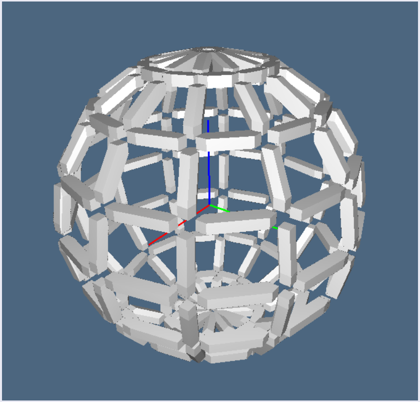
Minkowsky sum of cell complexes with a convex cell

def fun (poly): return COMP([EXPL([1.5,1.5,1.5]), SPLITCELLS, (OFFSET([.1,.1,.1])])(poly)

fun(SPHERE(1)([8,12]))



fun(SKELETON(1)(SPHERE(1)([8,12])))



Cartesian product on cell complexes

ACM/IEEE Symposium on Solid Modeling and Applications, 43–52. ACM Press, 1993.

a = 10*[1,-5]+[1];   b = MINUS(a);   P = PROD

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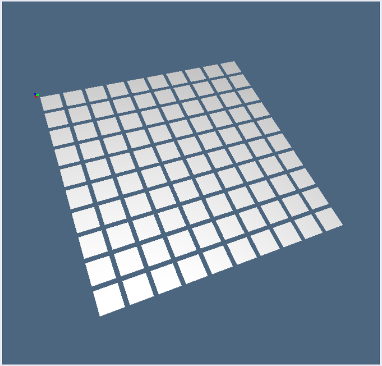
P([Q(b),Q(b)])



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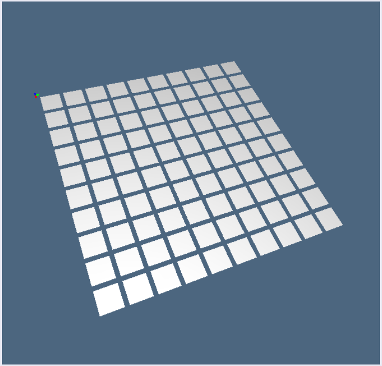
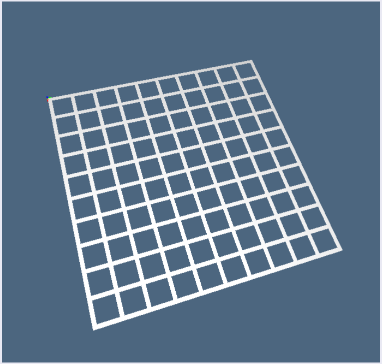


STRUCT([P([Q(a),Q(a)]), P([Q(a),Q(b)]), P([Q(b),Q(a)])])



Cartesian product on cell complexes

plan = PROD([Q(10), Q([5,5])]) section = MKPOL([[[0,4],[10,4],[10,7],[5,10],[0,7],[0,0],[10,0]], [[1,2,3,4,5],[1,2,6,7]], [[1],[2]]])

Cartesian product on cell complexes

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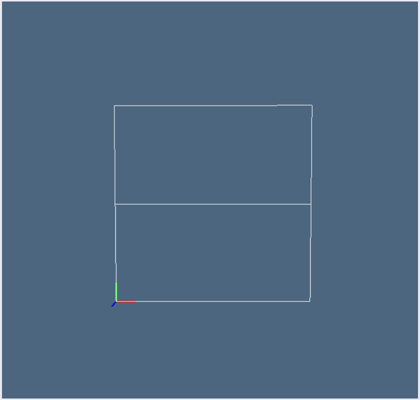
SK(1)(plan)



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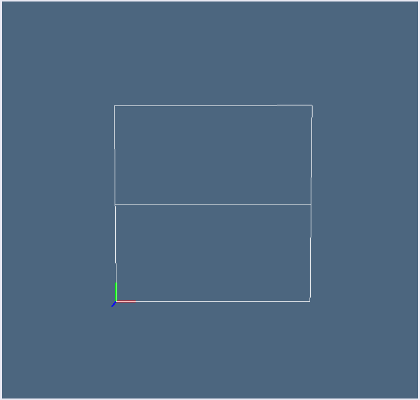
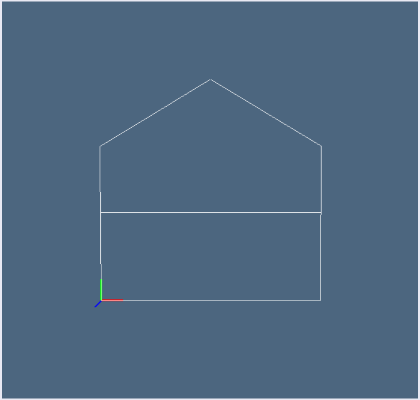


SK(1)(section)



Cartesian product on cell complexes

Intersection of extrusions.

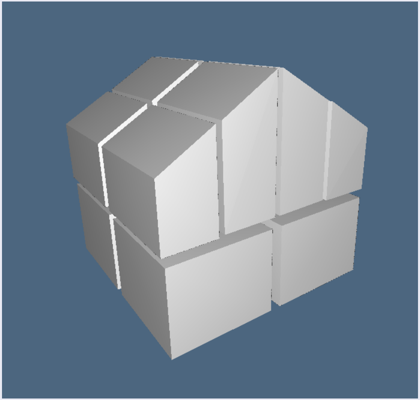
Special case of Cartesian product

Cartesian product on cell complexes

Intersection of extrusions. Special case of Cartesian product

house = GPROD([[1,2,3],[1,3,2]])([Obj1,Obj2])

EXPL([1.1,1.1,1.1])(SPLITCELLS(house))



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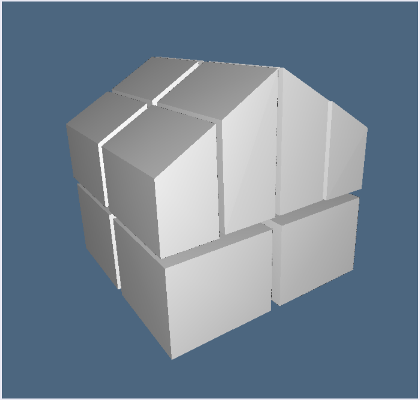
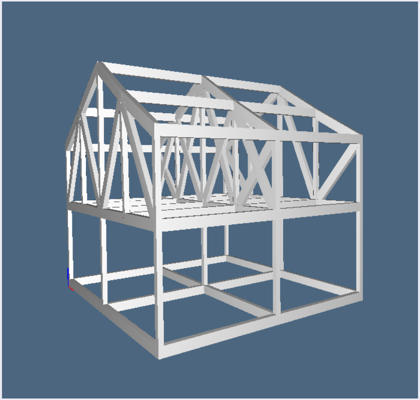


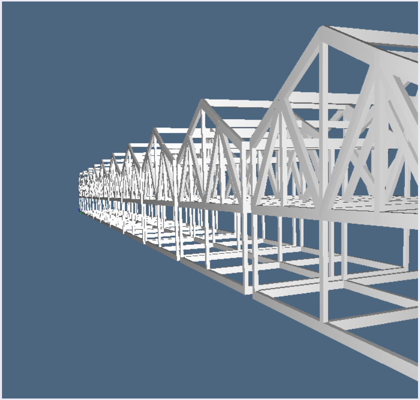
sk1 = OFFSET([.2,.2,.4])(SK(1)(house))



Scene graph of assemblies

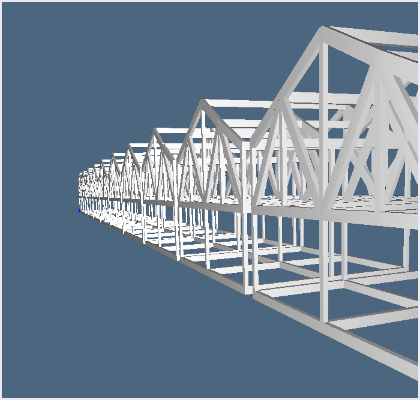
Scene graph of assemblies

str1 = STRUCT(10*[sk1,T(1)(11)])

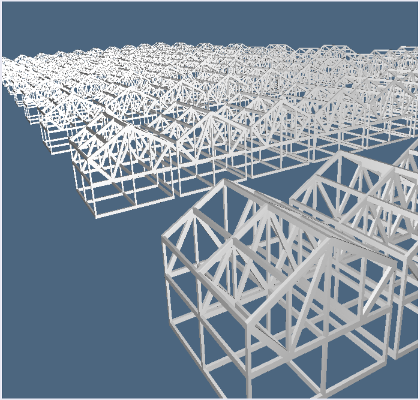


Scene graph of assemblies

str1 = STRUCT(10*[sk1,T(1)(11)])



str2 = STRUCT(10*[str1,T(2)(31)])



Chain complexes and Cochain complexes

- A chain complex is a sequence of linear spaces of d-chains, $0 \leq d \leq n$, with a sequence of boundary operators, each mapping the space of d-chains to the space of $(d-1)$-chains
- The dual of the chain complex is the cochain complex
- The duals of the boundary operators ∂ are the coboundary operator δ, that map the spaces of d-cochains to the spaces of $(d+1)$-cochains

Chain complexes and Cochain complexes

- All meshes, say partitioning either the boundary or the interior of a model, and their associated physical fields, are properly represented by a (co)chain complex.
- Such a complex therefore gives a complete discrete representation of any type of field over any type of geometric model.
- Huge geometric structures may be properly and efficiently represented by sparse matrices, and therefore efficiently manipulated through linear computational algebra, in particular by using the last-generation of highly parallel vector GPUs.

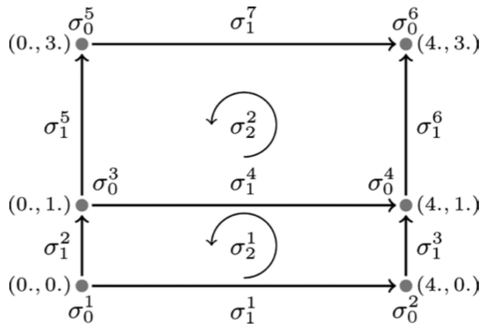
Chain complexes and Cochain complexes

This representation apply to all cell complexes

- The (co)chain representation captures formally and unambiguously all the combinatorial relationships of abstract, geometric, and physical modelling, via the standard topological operators of boundary and coboundary.
- This representation apply to all cell complexes, without restriction of type, dimension, codimension, orientability, manifoldness, etc.
- Furthermore, this approach unifies the geometric and physical computation in a common formal computational structure.

Chains/cochains over a cell complex

A small 2-complex



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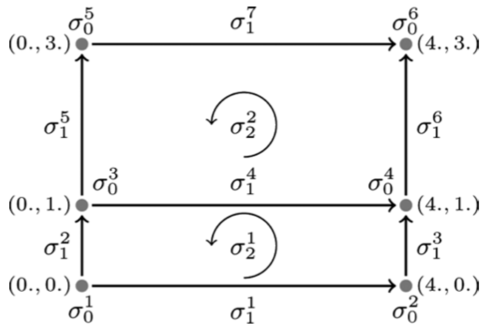

- Real-valued chains attach a signed *d*-measure to *d*-cells

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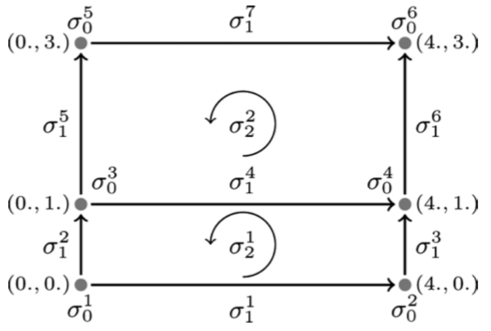

- Real-valued chains attach a signed *d*-measure to *d*-cells
- such as length to 1-cells, area to 2-cells, volume to 3-cells

Chains/cochains over a cell complex

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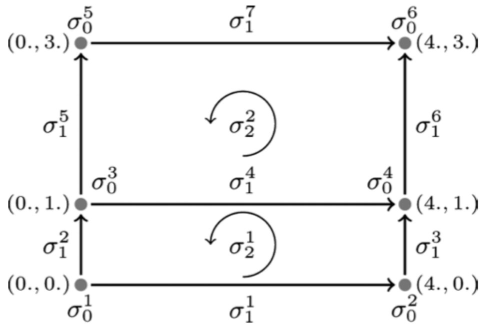


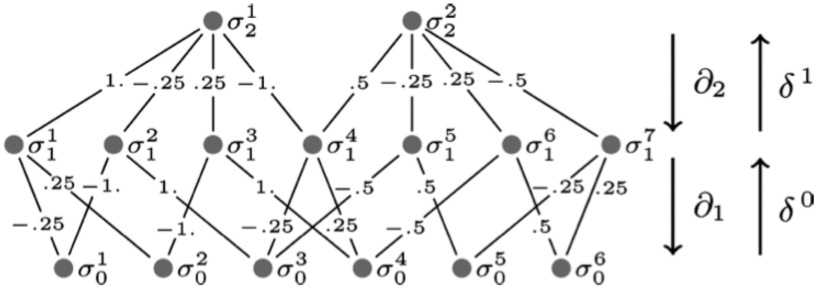
- Real-valued chains attach a signed *d*-measure to *d*-cells
- such as length to 1-cells, area to 2-cells, volume to 3-cells
- they restore part of the geometrical information left out by the purely topological construction of a cell complex

Hasse graph

Chains/cochains over a cell complex

already used in PyPlasm as the basic data structure

Hasse graph of the previous 2-complex

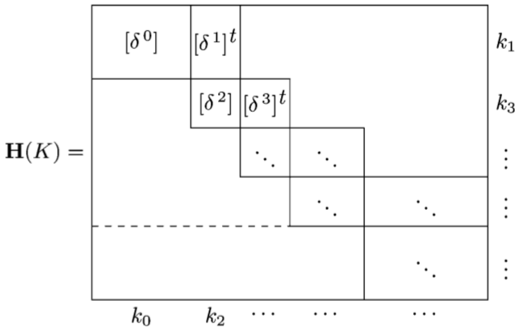


The Hasse matrix

A complete representation of the measured incidence between all cells of all dimensions

Discrete Physics using Metrized Chains. 2009. *SIAM/ACM Conf. on Geometric and Physical Modeling*

Block structure of the Hasse matrix



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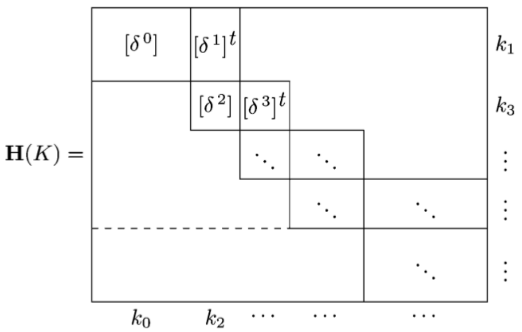

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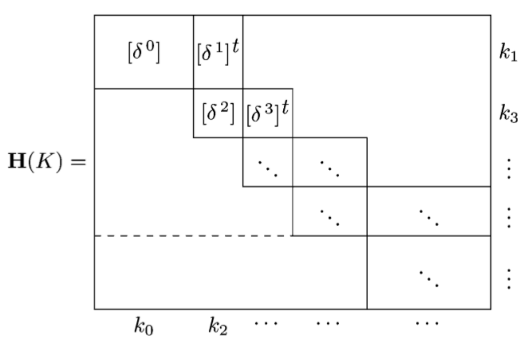

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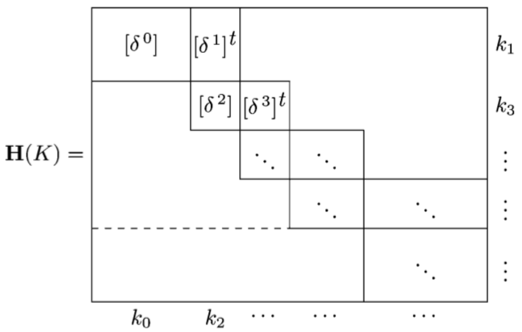

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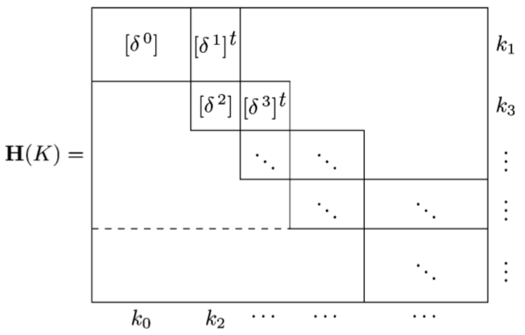

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Chompy

Python → Python ∪ Erlang

Chompy: to compute with (co)chain complexes using multi-paradigm and concurrent computer languages (Python and Erlang, respectively).

- —linear and higher order— dimension-independent simplicial complexes

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- and so on ...

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Concurrent processing done rigth

- Powerful (open source and multi-platform) concurrent functional programming language and runtime system

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- Developed by Ericsson to support distributed, fault-tolerant, soft real-time, non-stop applications

Disco: Erlang ∪ Python

Distributed computing framework developed by Nokia Research Center to solve real problems in handling massive amounts of data

- Disco users start Disco jobs in Python scripts.

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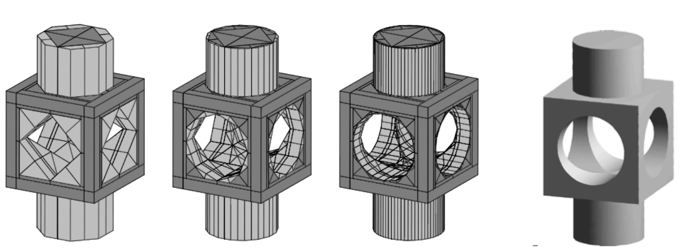
- Worker supervisors run Disco jobs as Python processes.

Progressive BSP (Binary Space Partition) tree

Back to Chompy dataflow streaming

3 types of geometry nodes: FULL, EMPTY and FUZZY cells



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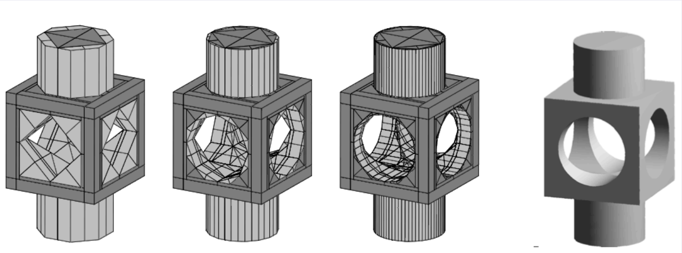

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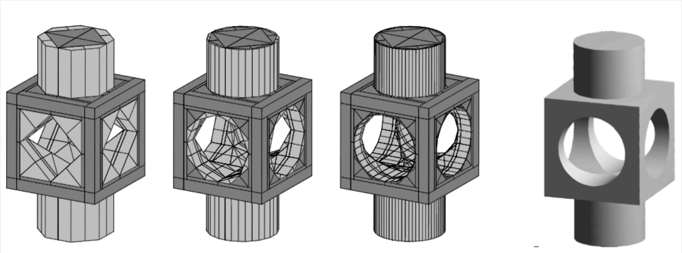

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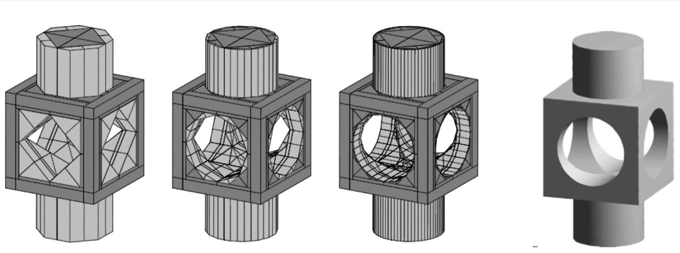
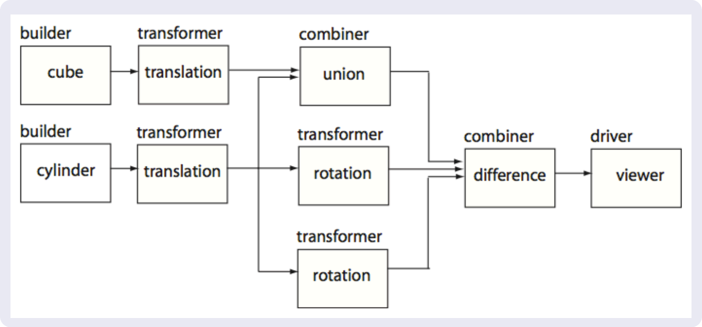


- The FUZZY cells, to be split at next step, are in light gray
- The FULL cells are in dark gray
- The EMPTY cells are not shown (of course :o)

Dataflow graph of the generating expression



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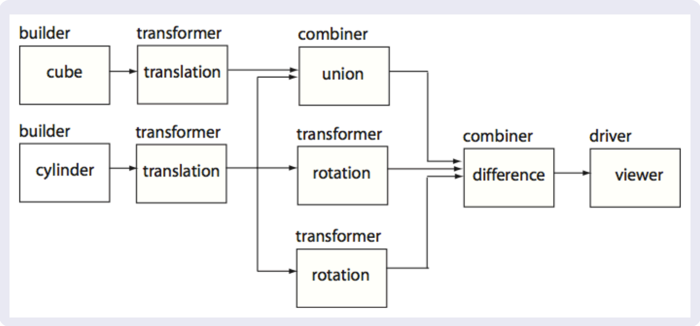

- Dataflow graph of the pyplasm expression that produces the mechanical piece

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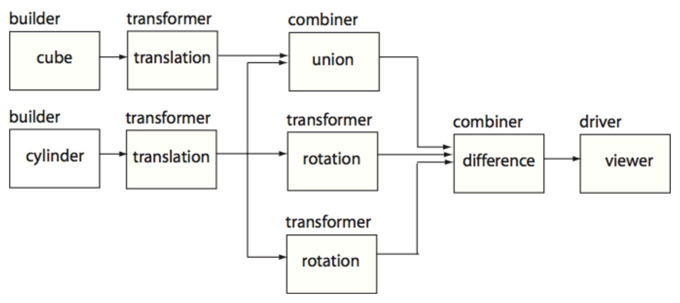

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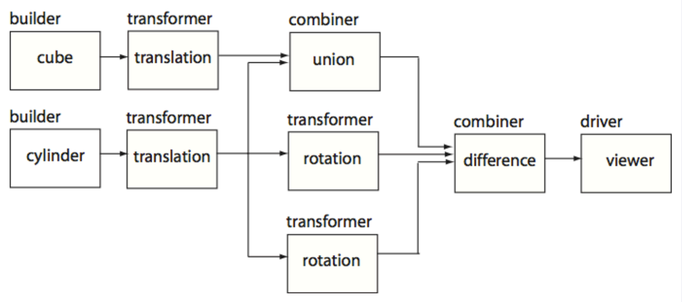
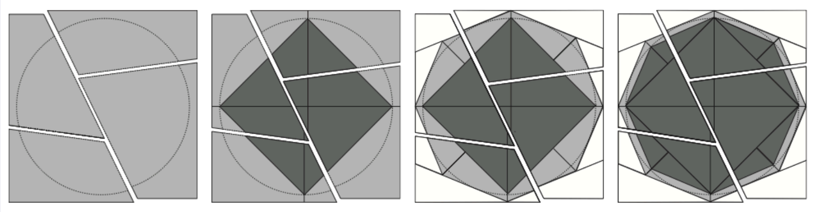


- Dataflow graph of the pyplasm expression that produces the mechanical piece
- The dataflow generation is from source preprocessing
- The various processes will run concurrently in an Erlang environment

Progressive BSP: generation of the 2-circle

Splitting of both (a) the model and (b) the computation



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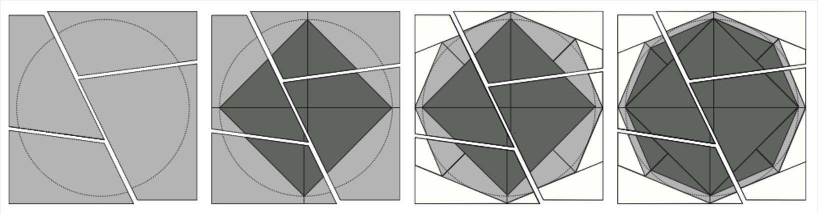

- Dataflow refinement based on progressive splits of convex cells with BSP tree nodes (hyperplanes)

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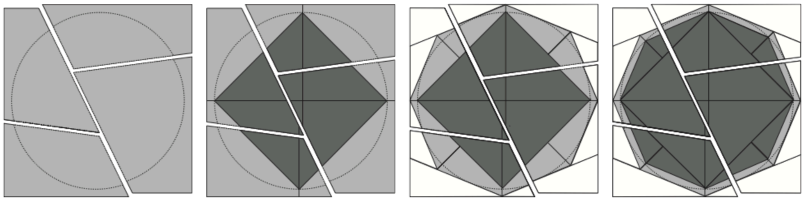
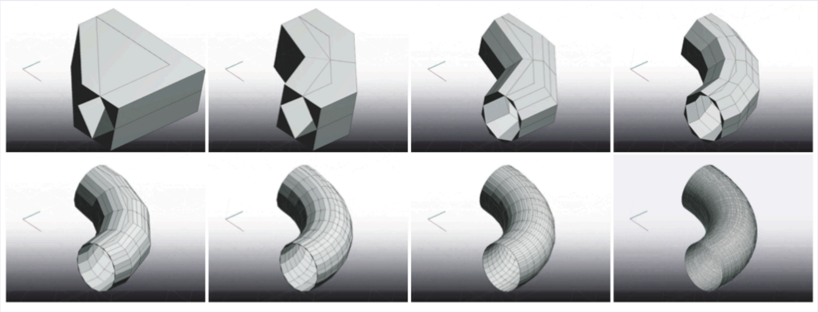


- Dataflow refinement based on progressive splits of convex cells with BSP tree nodes (hyperplanes)
- model partition induced by the BSP subtree closest to the root, to be detailed independently on different computational nodes

Progressive BSP: biquadratic rational B-spline



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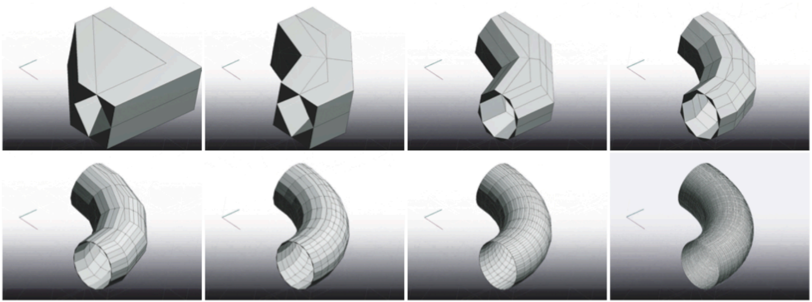

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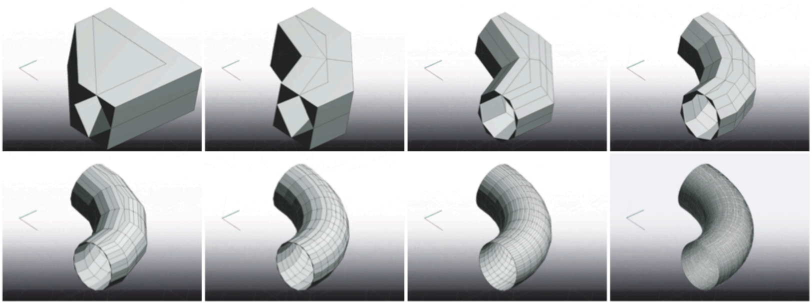
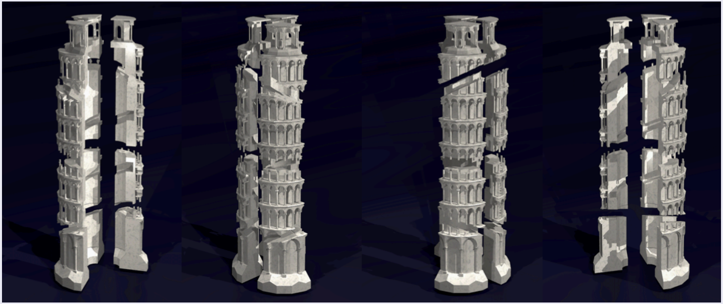


- each refinement is generated by splitting and is contained within the previous cell
- In this case (approximation of a surface with a solid mesh) all of the cells are either EMPTY or FUZZY, i.e. there are no solid cells

Progressive BSP: the Leaning tower of Pisa

Parallel solid modeling using BSP dataflow. 2008. *Journal of Comp. Geometry and Appl.*



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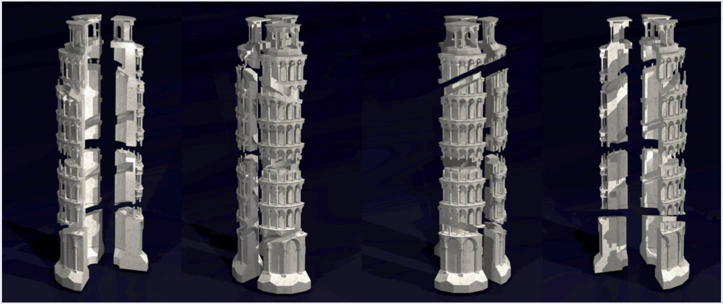

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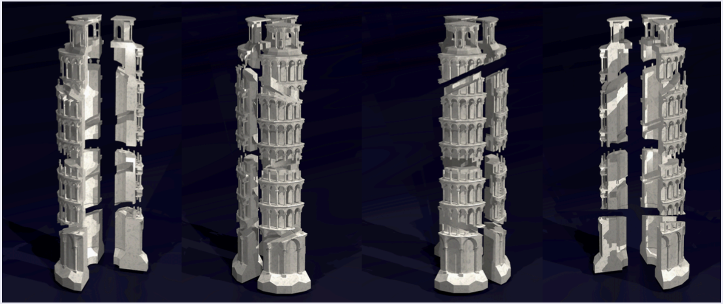

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The next step:

ProtoPlasm: A Parallel Language for Scalable Modeling of Biosystems. 2009. *Philosophical Transactions of the Royal Society A*, Vol. 366. Issue "The virtual physiological human: building a framework for computational biomedicine I"

Thanks for your attention !!