Declarative Language for Geometric Pattern Matching in VLSI Process Rule Modeling

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Intel Corporation

Regular Expressions

```
[Aa][ie]ro?plane  << pattern of interest
```

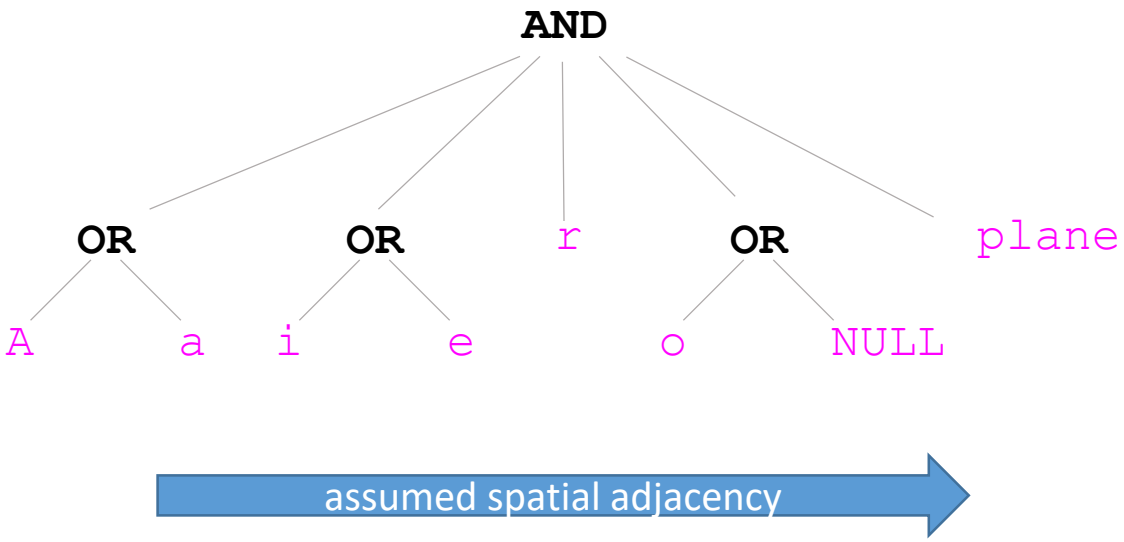
```
Airplane
aeroplane
aerooplane
```

Which one of these words will match the regular expression?

Regular Expressions

```
[Aa][ie]ro?plane  << pattern of interest

Airplane   << match
aeroplane  << match
aerooplane << no match
```




```
AND
  OR
    A
    a
  OR
    i
    e
  r
  OR
    o
    NULL
  plane
```

Regular Expressions

```
([Aa][ie]ro?plane ){2}  << pattern of interest
```

I'm just a aeroplane poor boy and nobody loves me, He's just a poor boy from a poor family, Spare him his life from this monstrosity, Easy come easy go will you let me go, Bismillah, Airplane aeroplane no we will aiirplane not let you go, let him go, Bismillah, we will not let you go, Airplane let him go, Bismillah, we will not airpplan let you go, let me go, (Will not let you go) let me go (never, never let you go) let me Airplane Aeroplane go (never let me go), Oh oh no, no, no, no, no, no, no, Oh mama mia, mama mia, mama mia let me go, Beelzebub has a devil put aside for me for me for me for me aeroplane Airplane for me airplane for you Airplane for them aeroplane.

Regular Expressions

```
([Aa][ie]ro?plane ){2}  << pattern of interest
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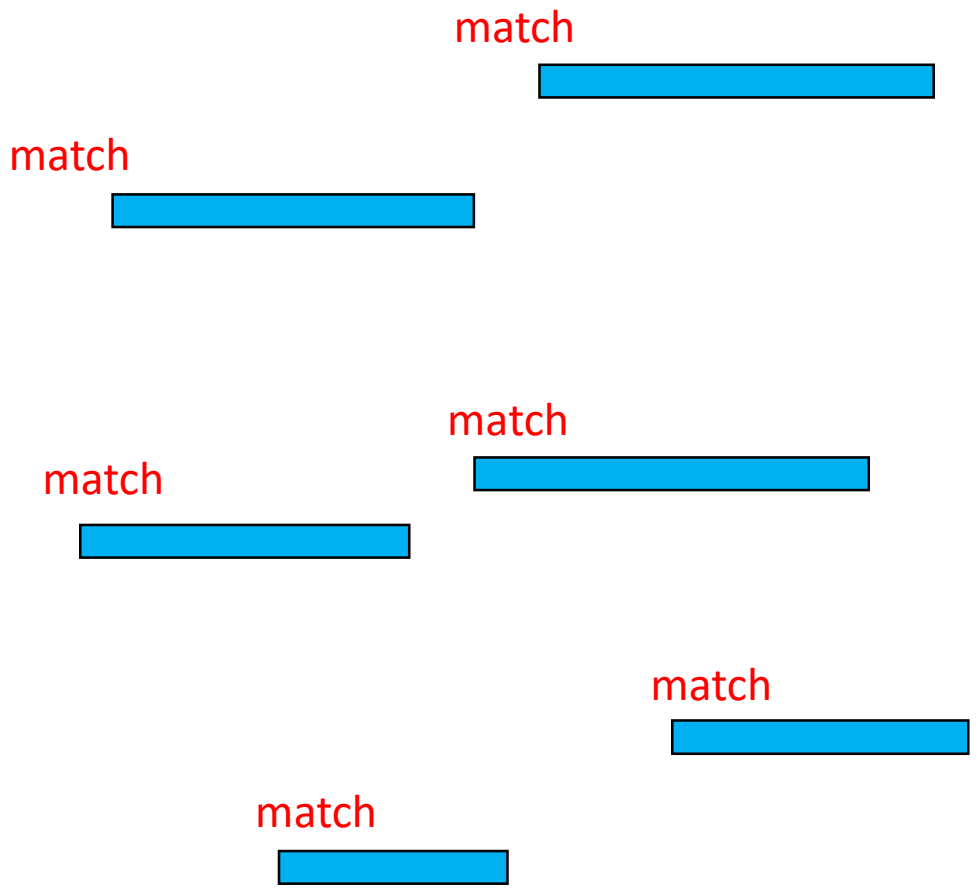
- Formal
- Non-ambiguous
- Expressive
- Compact
- Can be typed in by non-programmers
- Wouldn’t it be nice to have to a similar language for VLSI layout patterns?

Simple Example

```
Type Fuselage Wire layer=metal2 orient=H dy=10

Pattern Airplane
AND
   f Fuselage ; there exists a fuselage
```

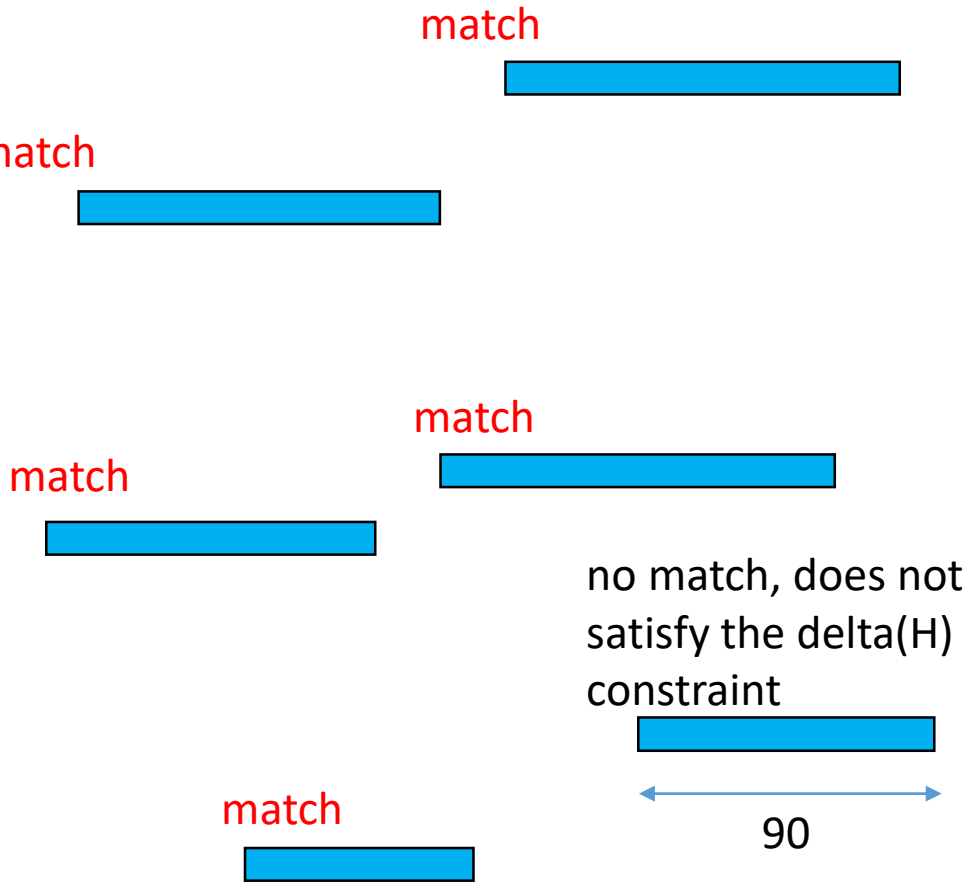


Simple Example

```
Type Fuselage Wire layer=metal2 orient=H dy=10

Pattern Airplane
AND
  f Fuselage | f.delta(H) in {70, [100, 120], 140}
```

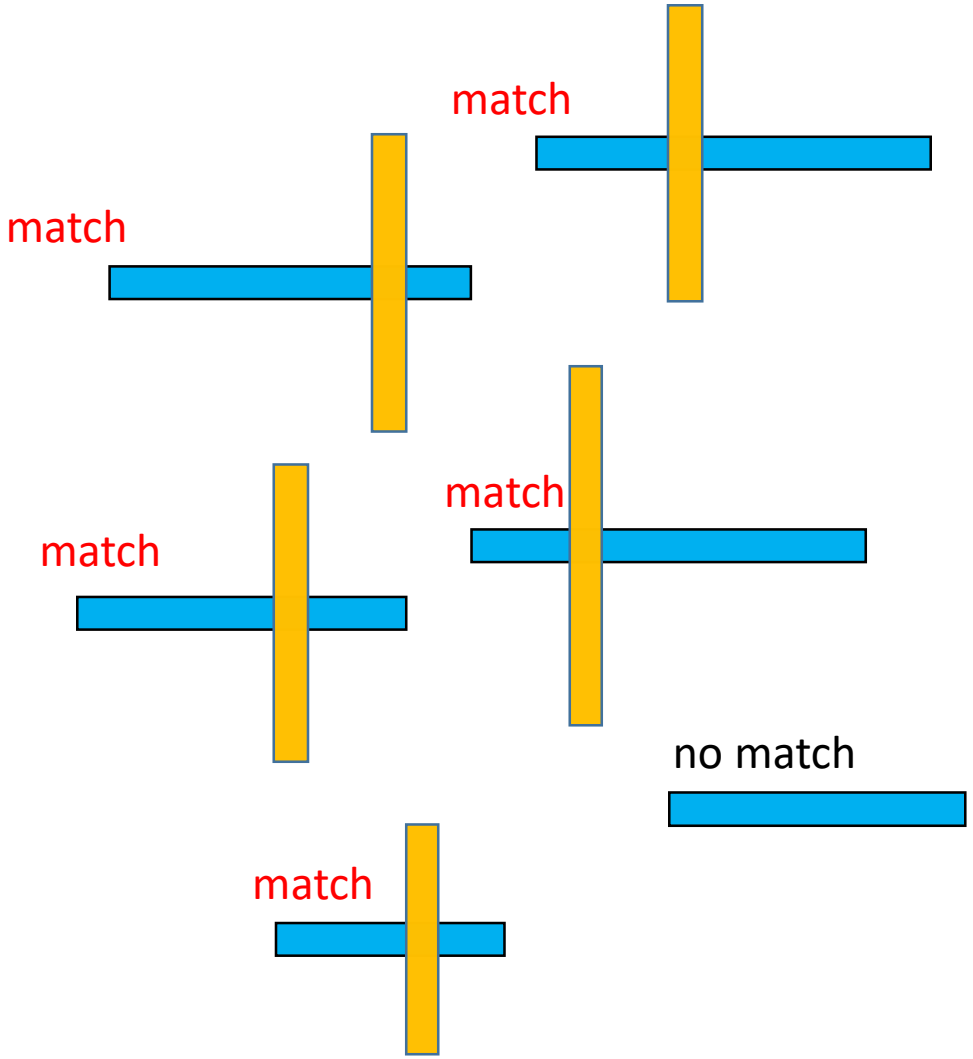
guard expression
such-that horizontal dimension
is in the given interval set



Simple Example

```
Type Wing      Wire layer=metal1 orient=V

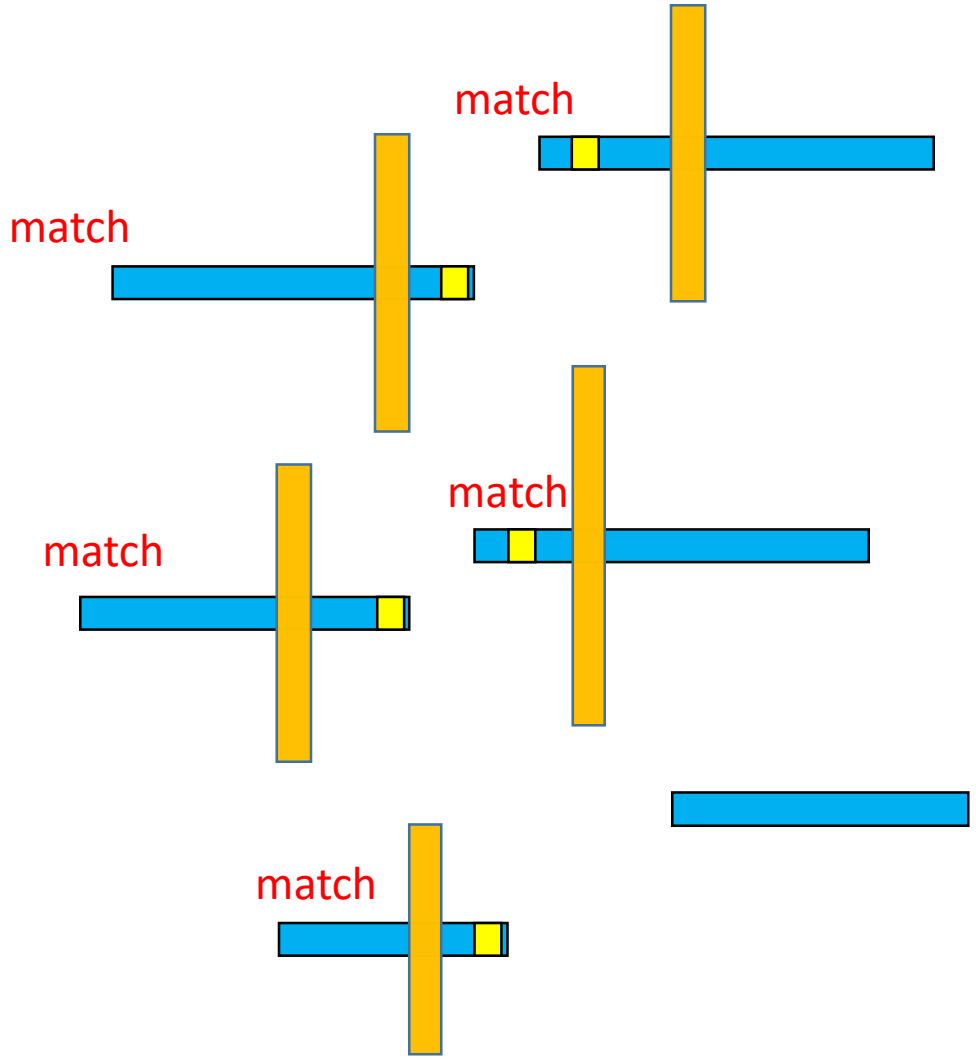
Pattern Airplane
AND
   f Fuselage | f.delta(H) in {70, [100, 120], 140}
   w Wing     | w.delta(V) in [70, 110]
                w.yc == f.yc
                f.contains(w, H)
```



Simple Example

```
Type Cockpit  Via  layer=via2

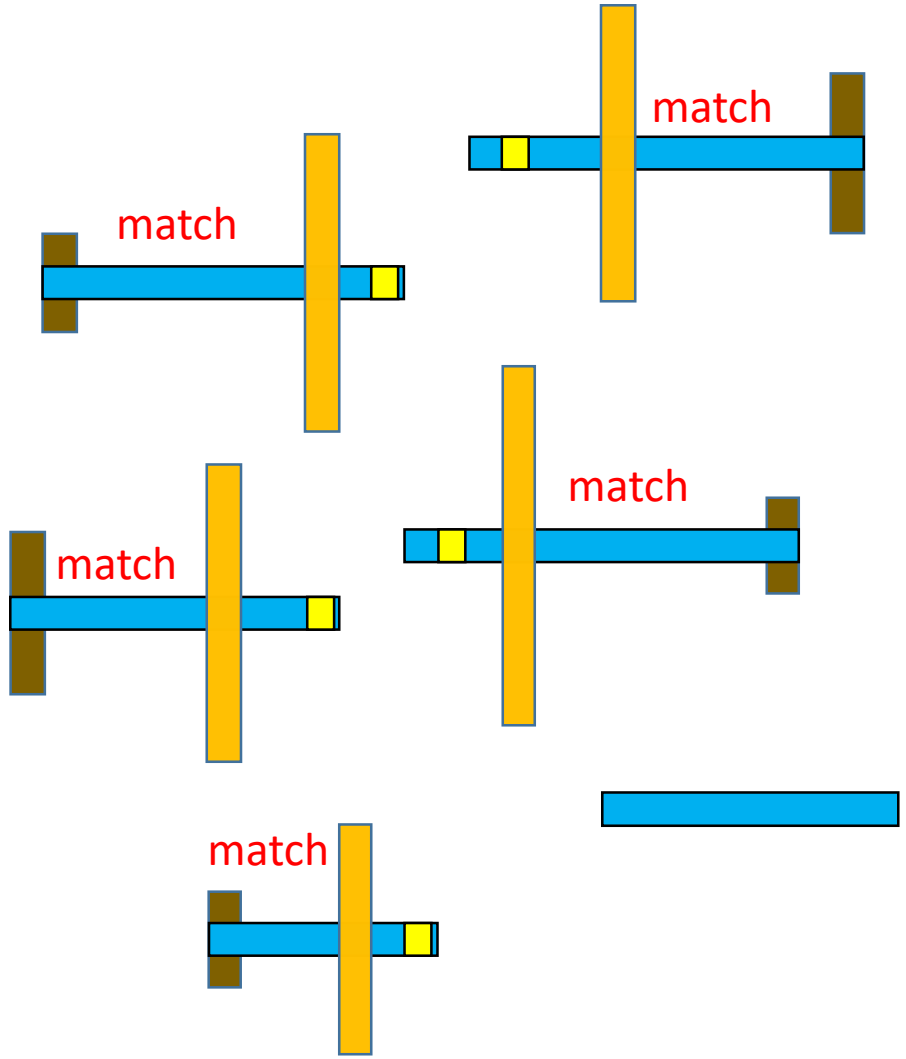
Pattern Airplane
AND
  f Fuselage | f.delta(H) in {70, [100, 120], 140}
  w Wing     | w.delta(V) in [70, 110]
               w.yc == f.yc
               f.contains(w, H)
  p Cockpit  | f.contains(p)
               NOT w.intersects(p)
```



Example of a Complete Airplane

```
Type Tail      Wire layer=metal3 orient=V

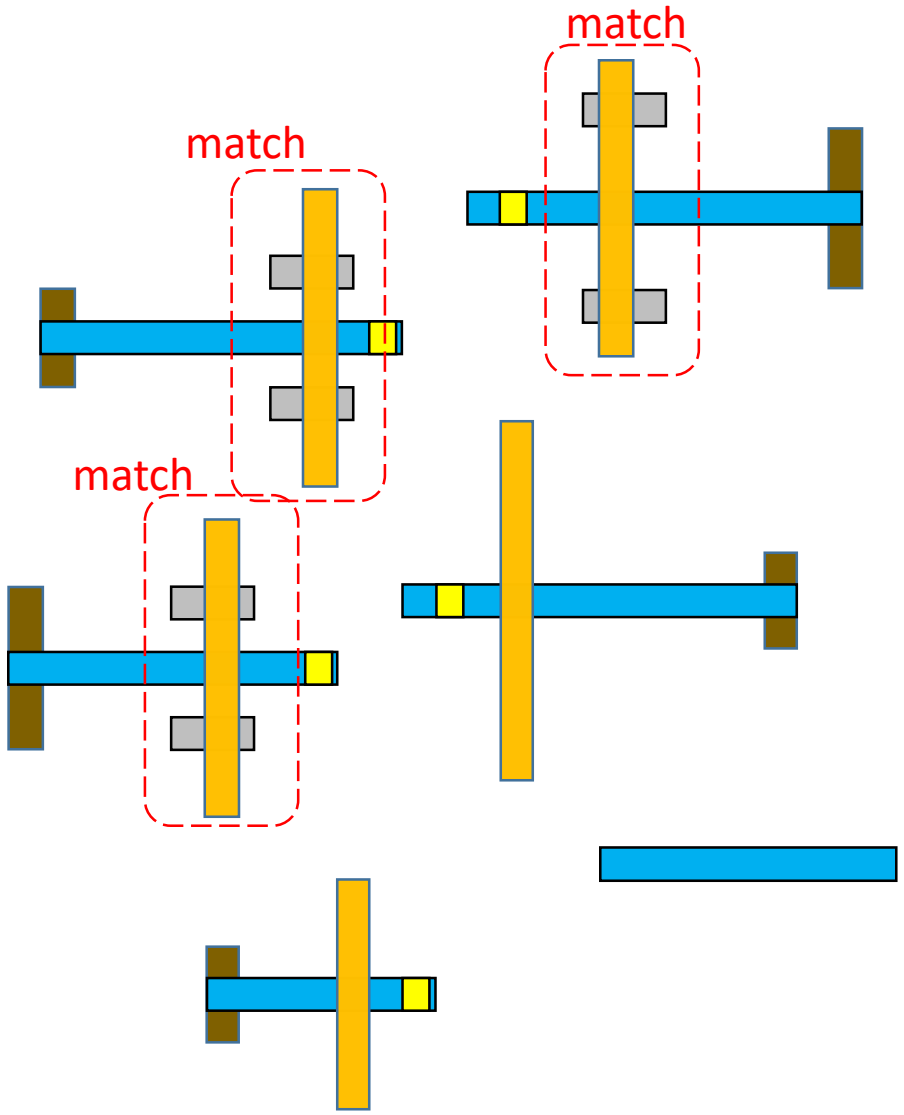
Pattern Airplane
AND
   f Fuselage | f.delta(H) in {70, [100, 120], 140}
   w Wing     | w.delta(V) in [70, 110]
                w.yc == f.yc
                f.contains(w, H)
   p Cockpit  | f.contains(p)
                NOT w.intersects(p)
   t Tail     | t.yc == f.yc
                f.contains(t, H)
```



Wing With Engines Pattern

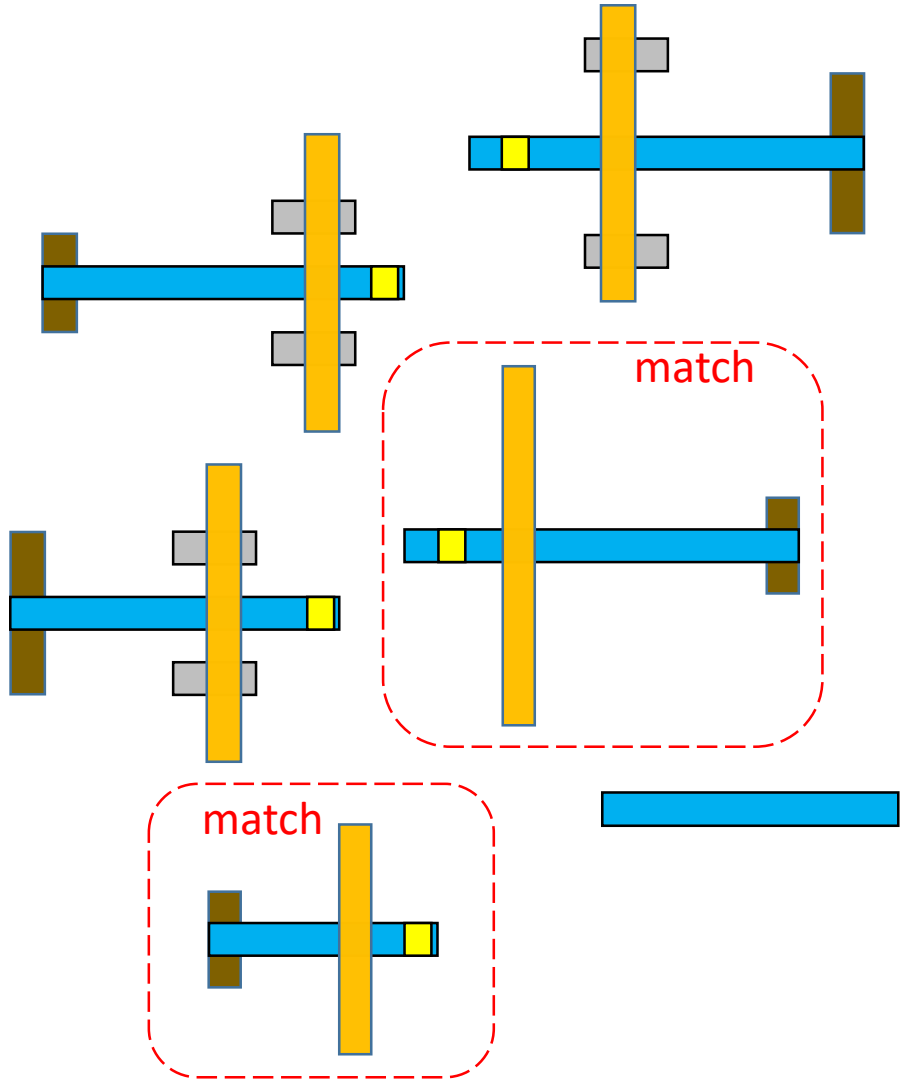
```
Type Engine    Wire layer=metal4 orient=H

Pattern WingWithEngines
AND
   w Wing
   e1, e2 Engine | w.contains(this, V)
                   this.contains(w, H)
   e1.generalized_intersection(e2).yc == w.yc
```



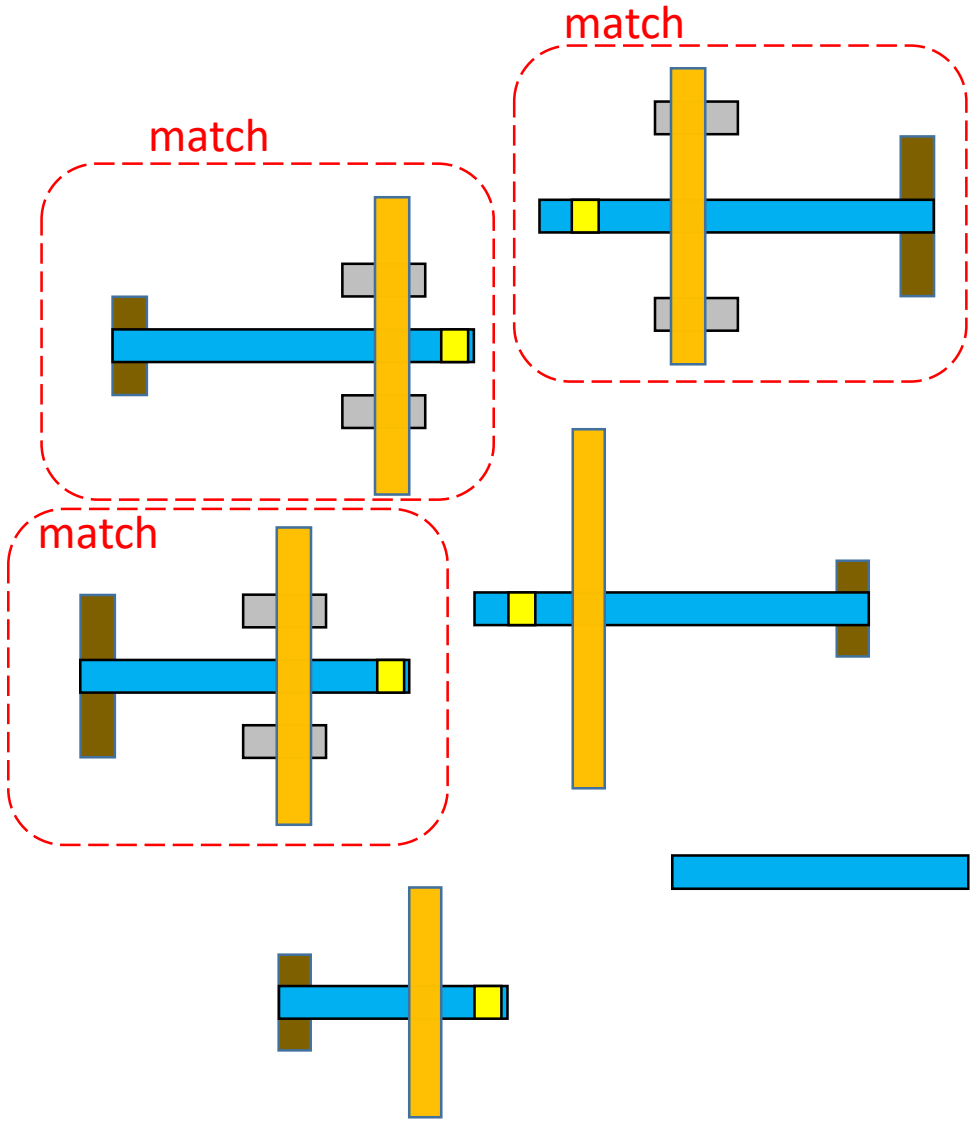
Glider Pattern

```
Pattern Glider
AND
   a Airplane
   ; there does not exist a WingWithEngines
   ; such-that its wing is identical
   ; with a's wing
   NOT w WingWithEngines | w.w == a.w
```



Jet Pattern

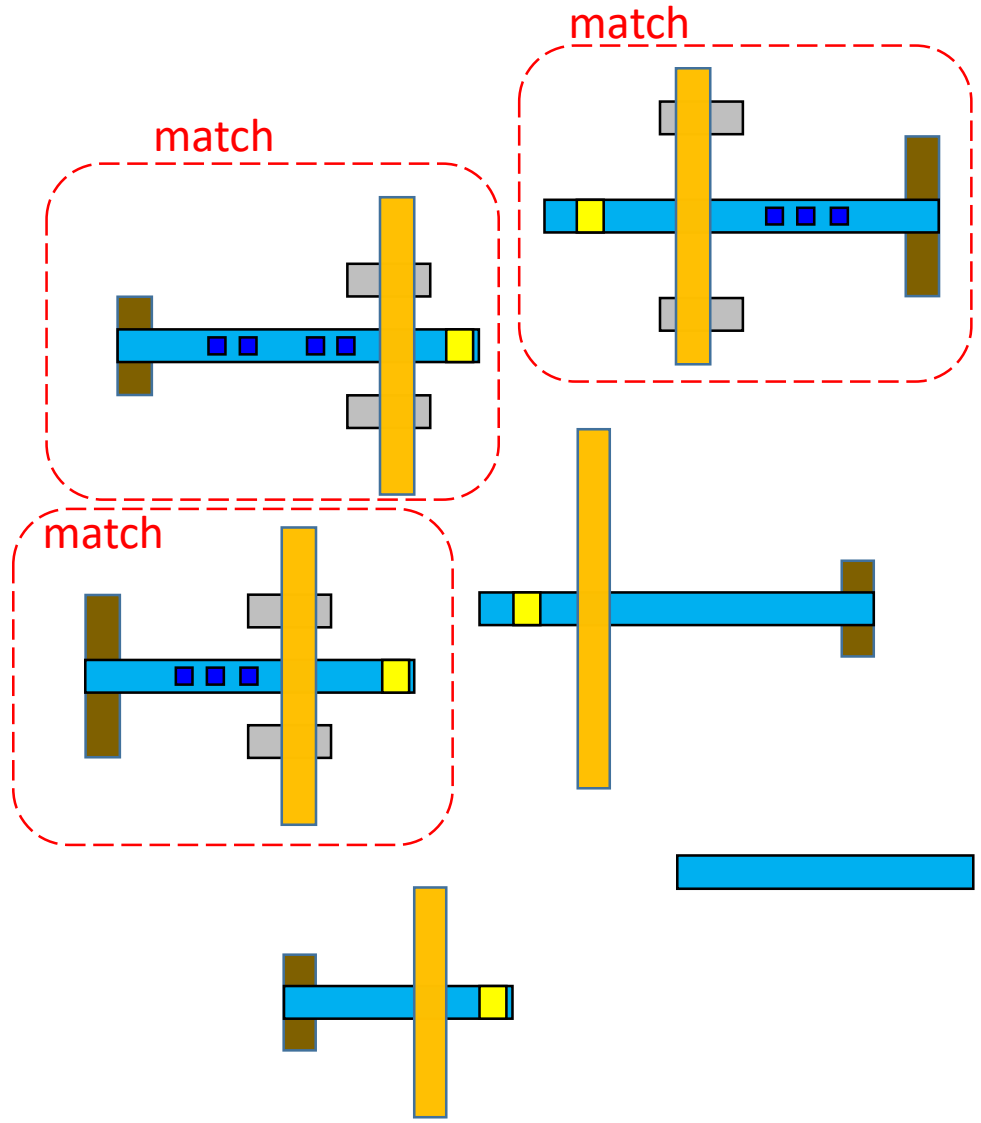
```
Pattern Jet
AND
   a Airplane
   ; there does exist a WingWithEngines
   ; such-that its wing is identical
   ; with a's wing
   w WingWithEngines | w.w == a.w
```



Jet Pattern, with Windows

```
Type Window   Via  layer=via1

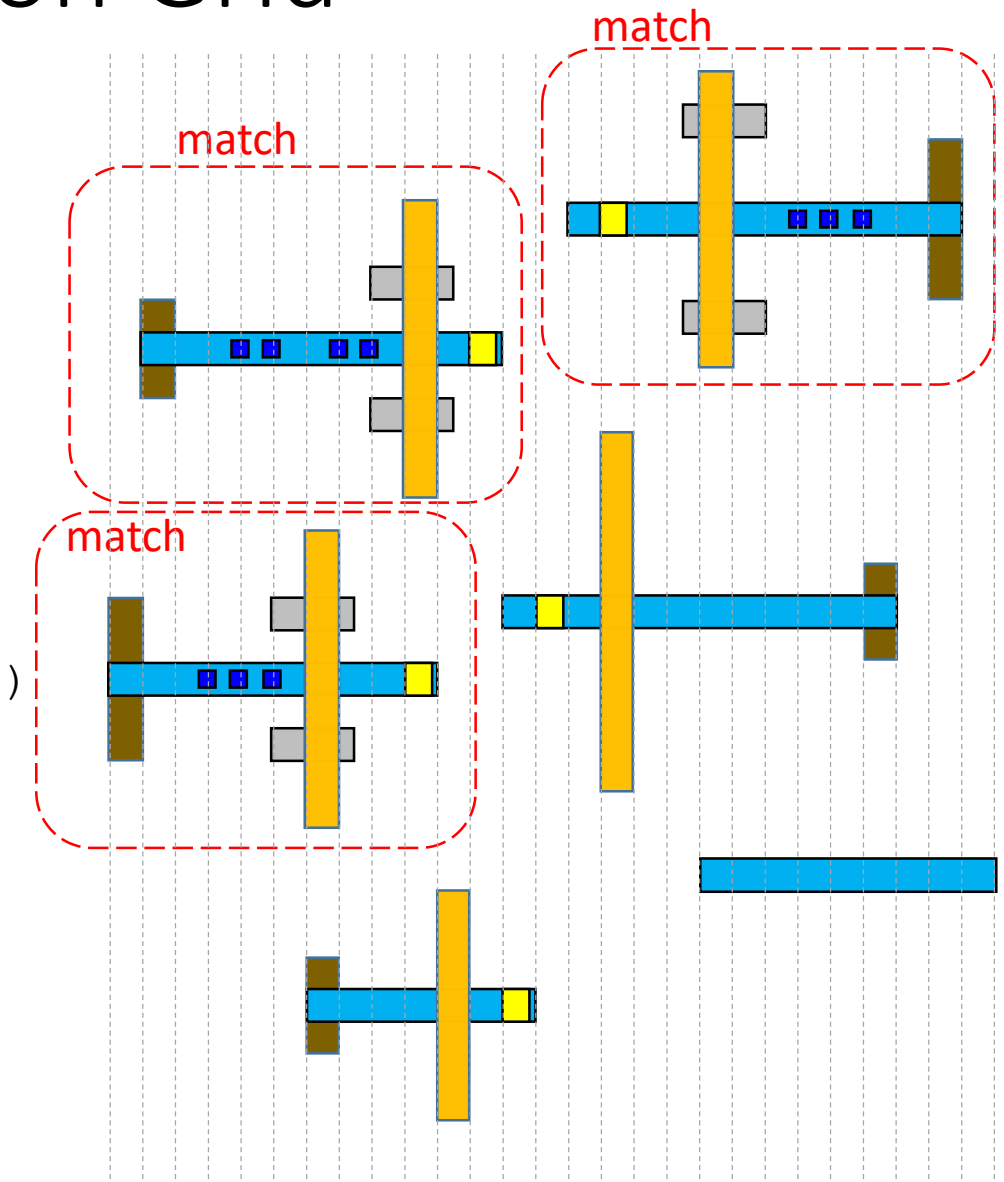

Pattern Jet
AND
  a Airplane
  ; there does exist a WingWithEngines
  ; such-that its wing is identical
  ; with a's wing
  w WingWithEngines | w.w == a.w
  let windows = Set {Window} | a.f.contains(this)
  windows.count in [3, 5]
```



Jet Pattern, with Windows on Grid

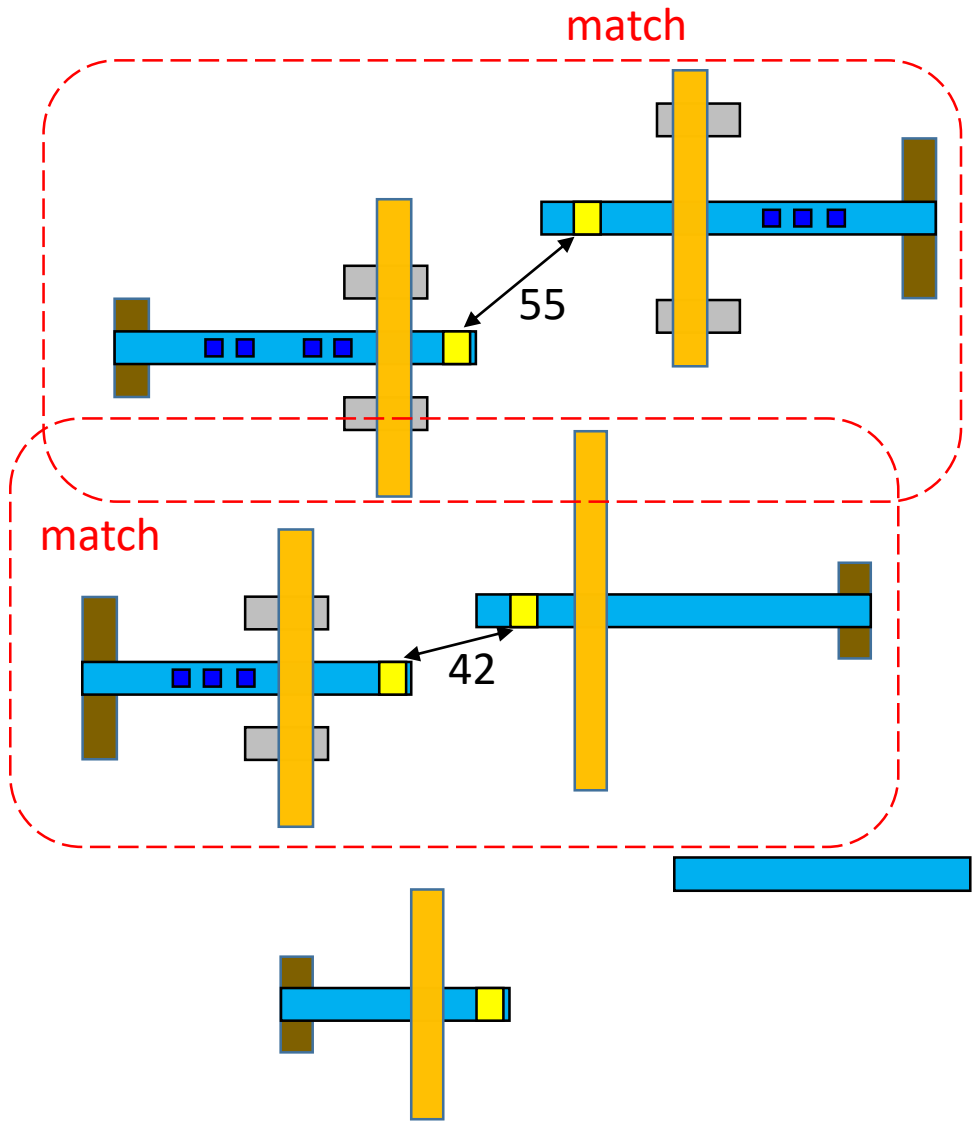
```
Grid g offset=0 period=10 orient=V

Pattern Jet
AND
  a Airplane
  ; there does exist a WingWithEngines
  ; such-that its wing is identical
  ; with a's wing
  w WingWithEngines | w.w == a.w
  let windows = Set {Window} | a.f.contains(this)
                                this.xc on g
  windows.count in [3, 5]
```



Formation Pattern

```
Pattern Formation
AND
   a1 Jet
   a2 {Jet, Glider} ; a2 is Jet or Glider
   a1.a.p.euclidean_distance(a2.a.p) < 60
```

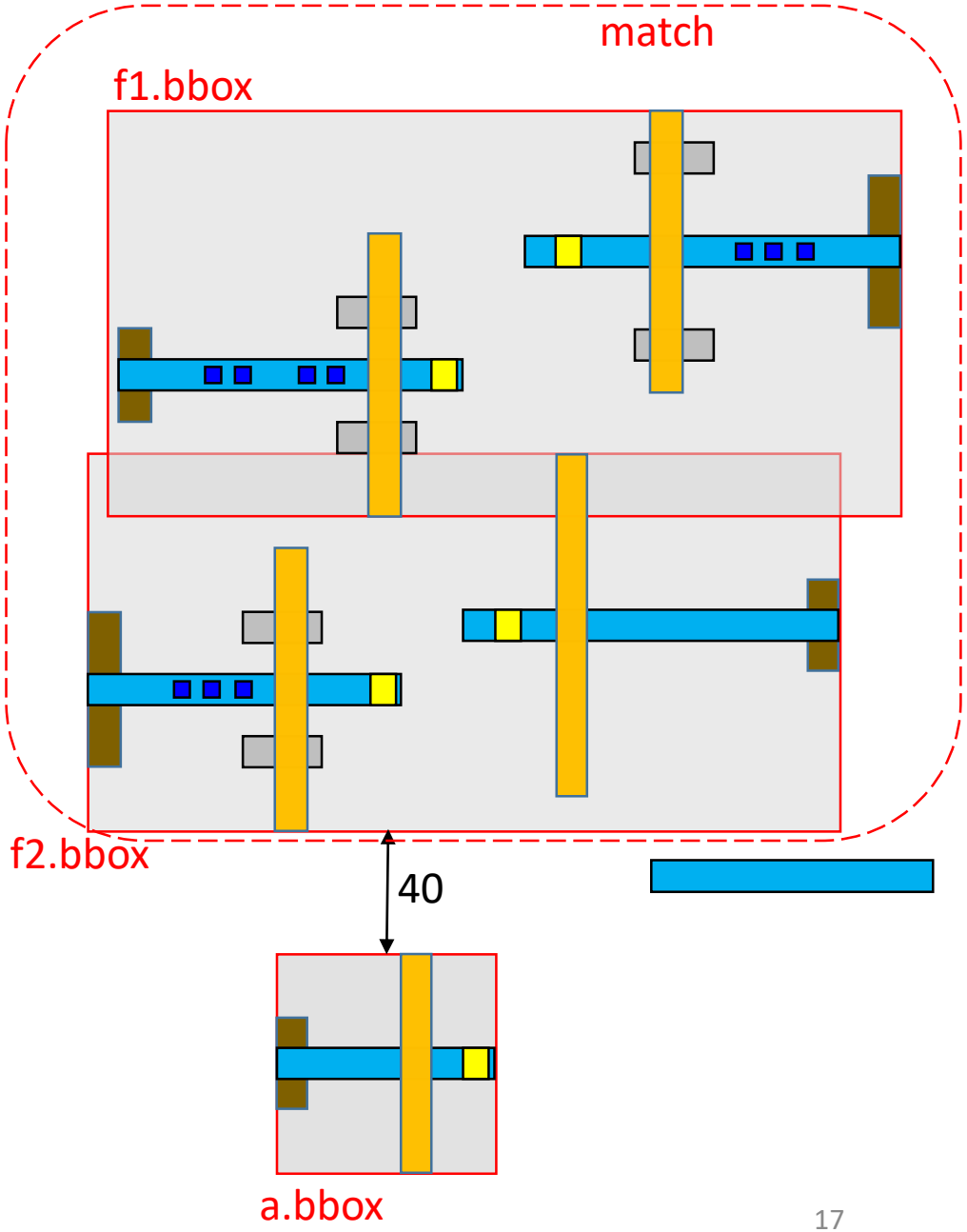


CloseFormations Pattern

```
Rule CloseFormations
AND
   f1, f2 Formation
   f1.bbox.intersects(f2.bbox)

   ; there does not exist an airplane a
   NOT a Airplane |
      OR
         a.bbox.spacing(f1.bbox,V)< 20
         a.bbox.spacing(f2.bbox,V)< 20
```

false
false
false
true
true



CloseFormations Pattern

```
Rule CloseFormations
AND
   f1, f2 Formation
   f1.bbox.intersects(f2.bbox)

   ; there does not exist an airplane a
   NOT a Airplane |
      OR
         a.bbox.spacing(f1.bbox,V)< 20   false
         a.bbox.spacing(f2.bbox,V)< 20   true
```

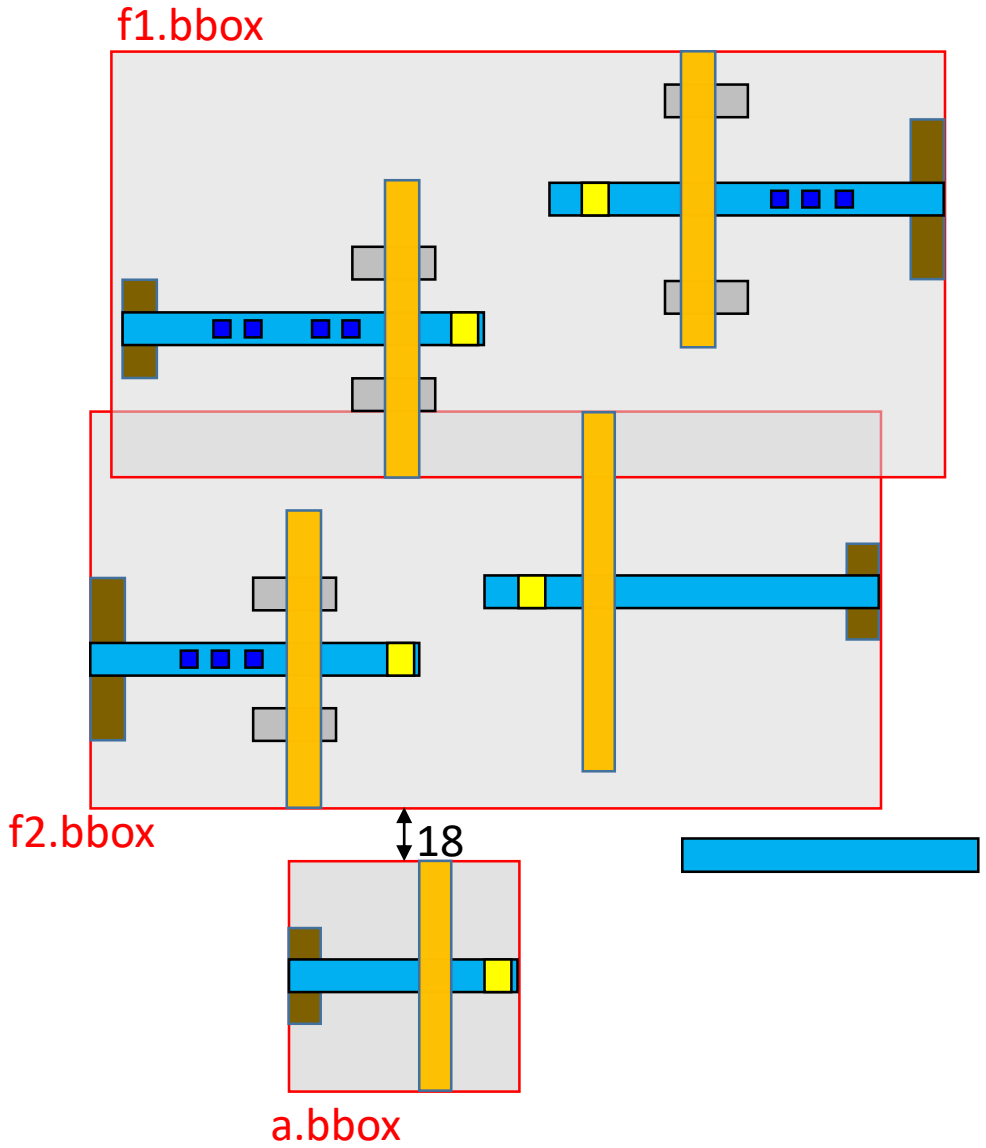
true

true

false

false

no match

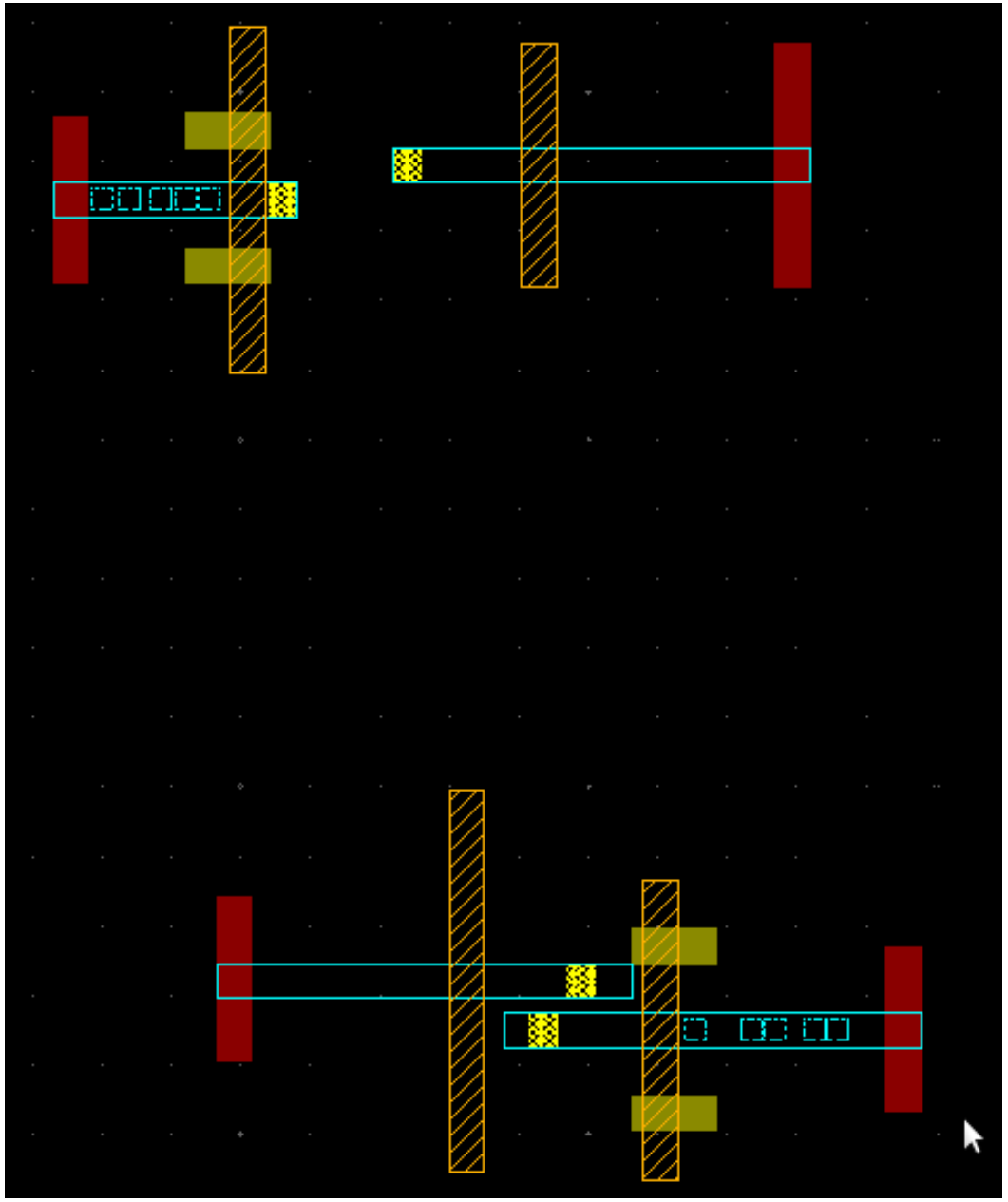


Automatic Test Layout Generation

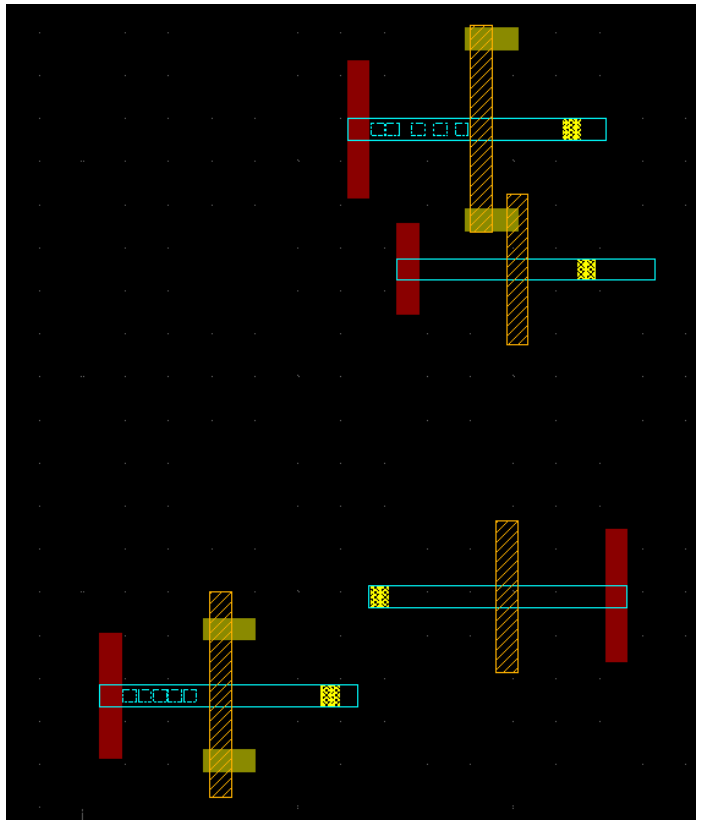
```
Pattern Formation
AND
   a1 Jet
   a2 Glider
   a1.a.p.euclidean_distance(a2.a.p) < 60

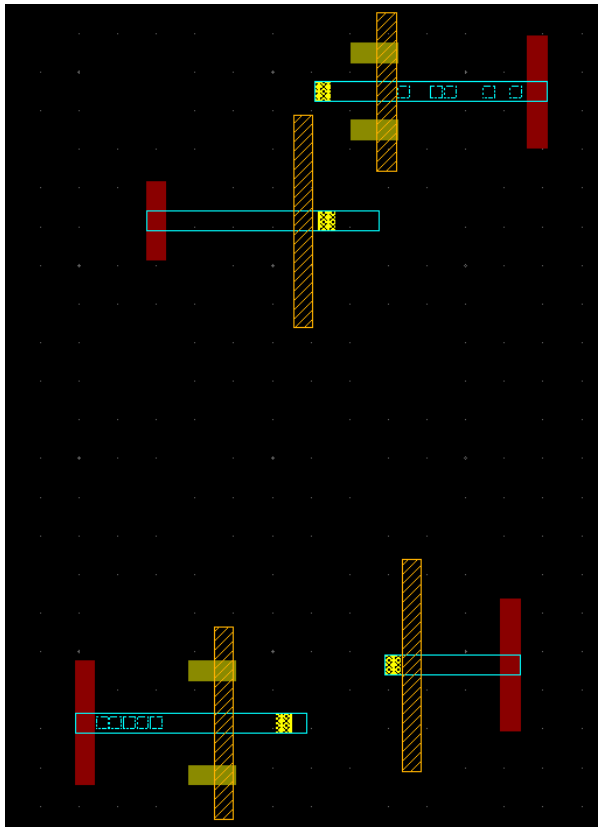
Rule CloseFormationsSimplified
AND
   f1, f2 Formation
   f1.bbox.spacing(f2.bbox, V) in [150, 300]
```

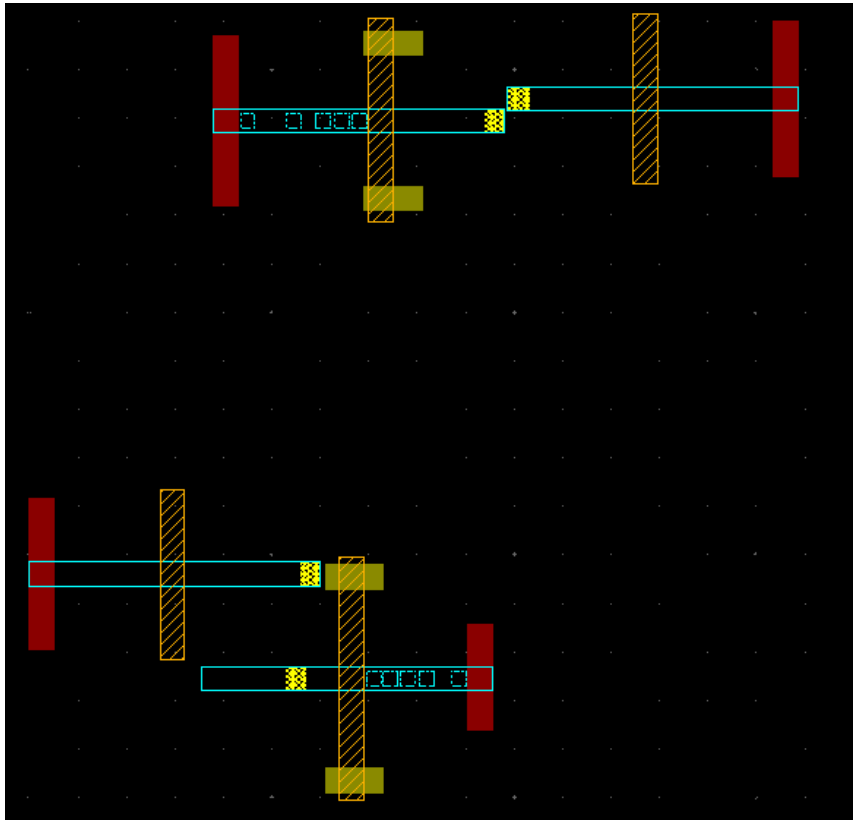
Test Layout Automatically Generated from the rule above



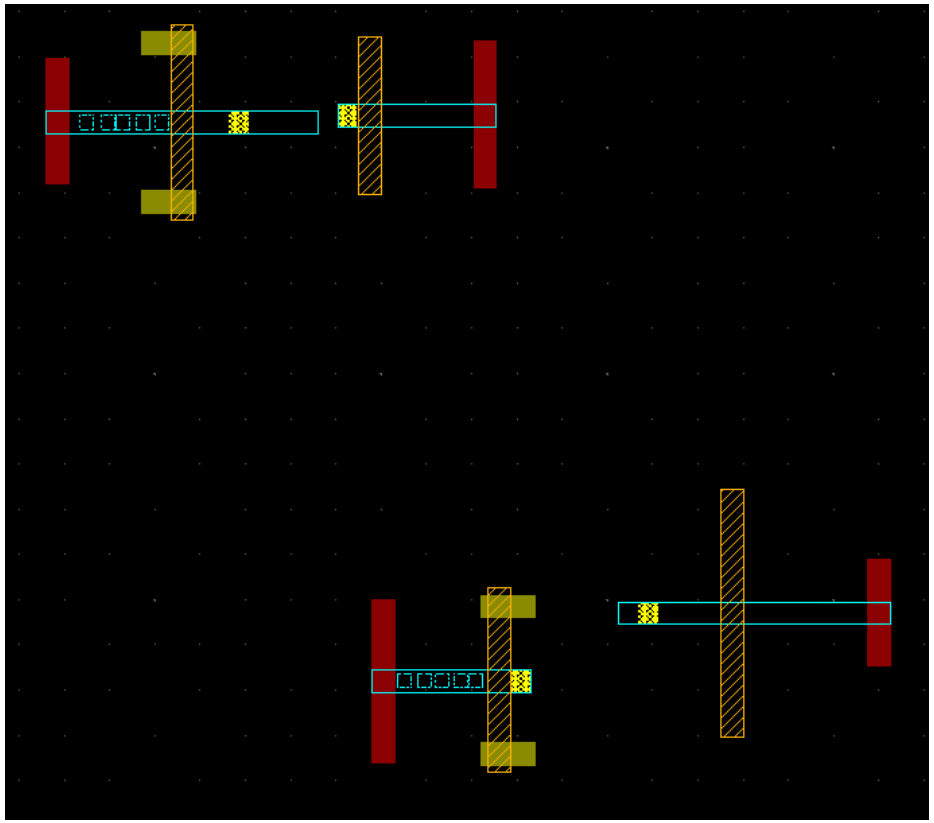
More Auto-generated Test Layouts

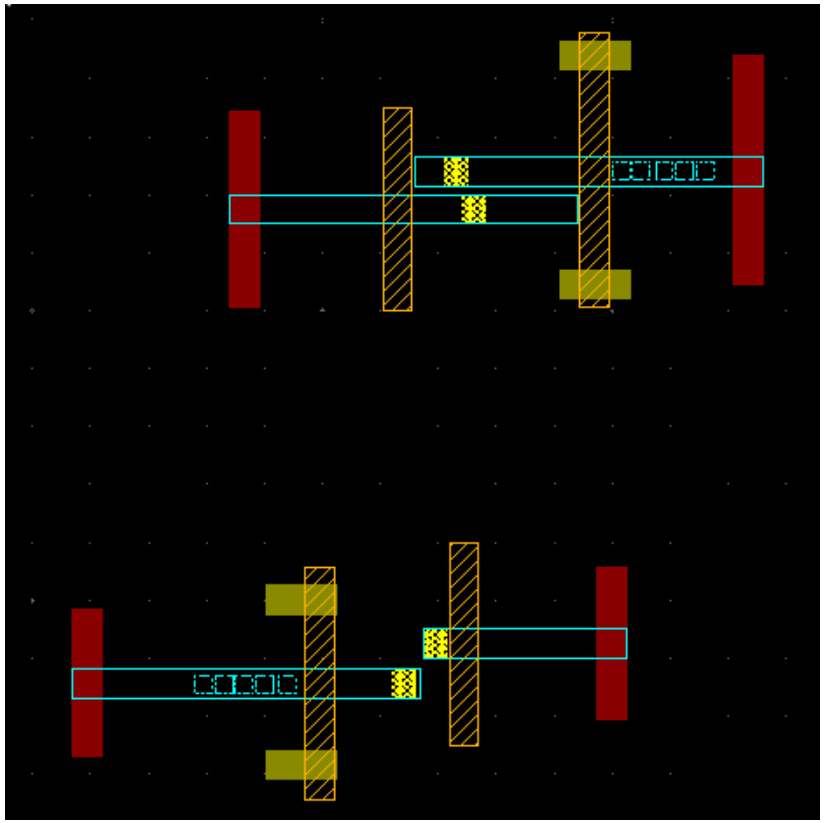


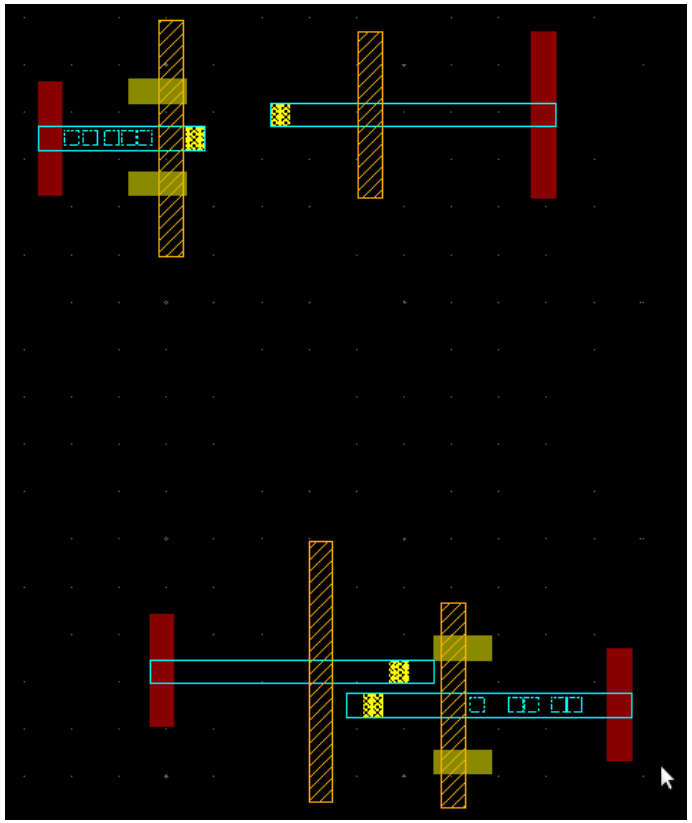




More Auto-generated Test Layouts, cont'd

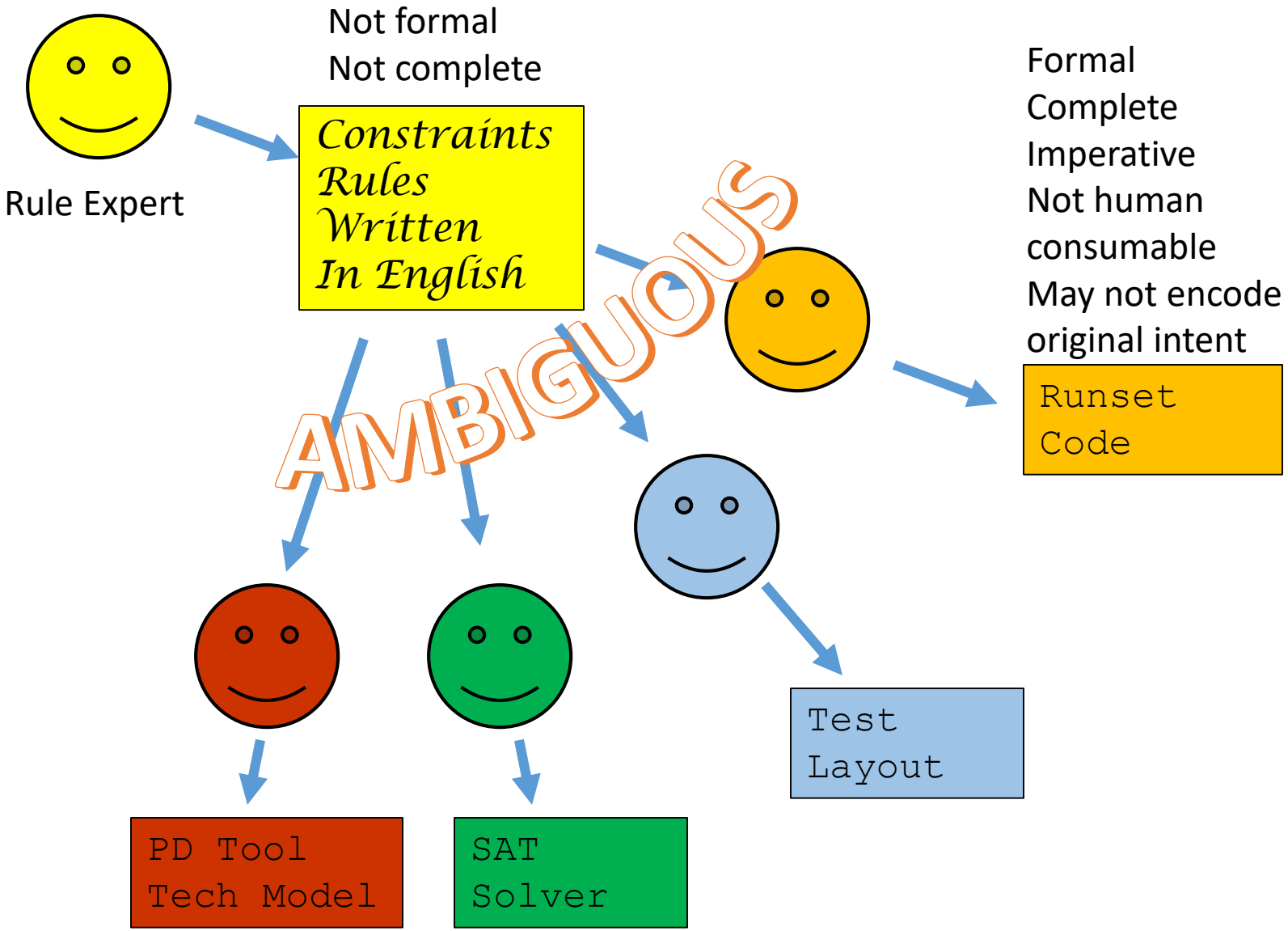






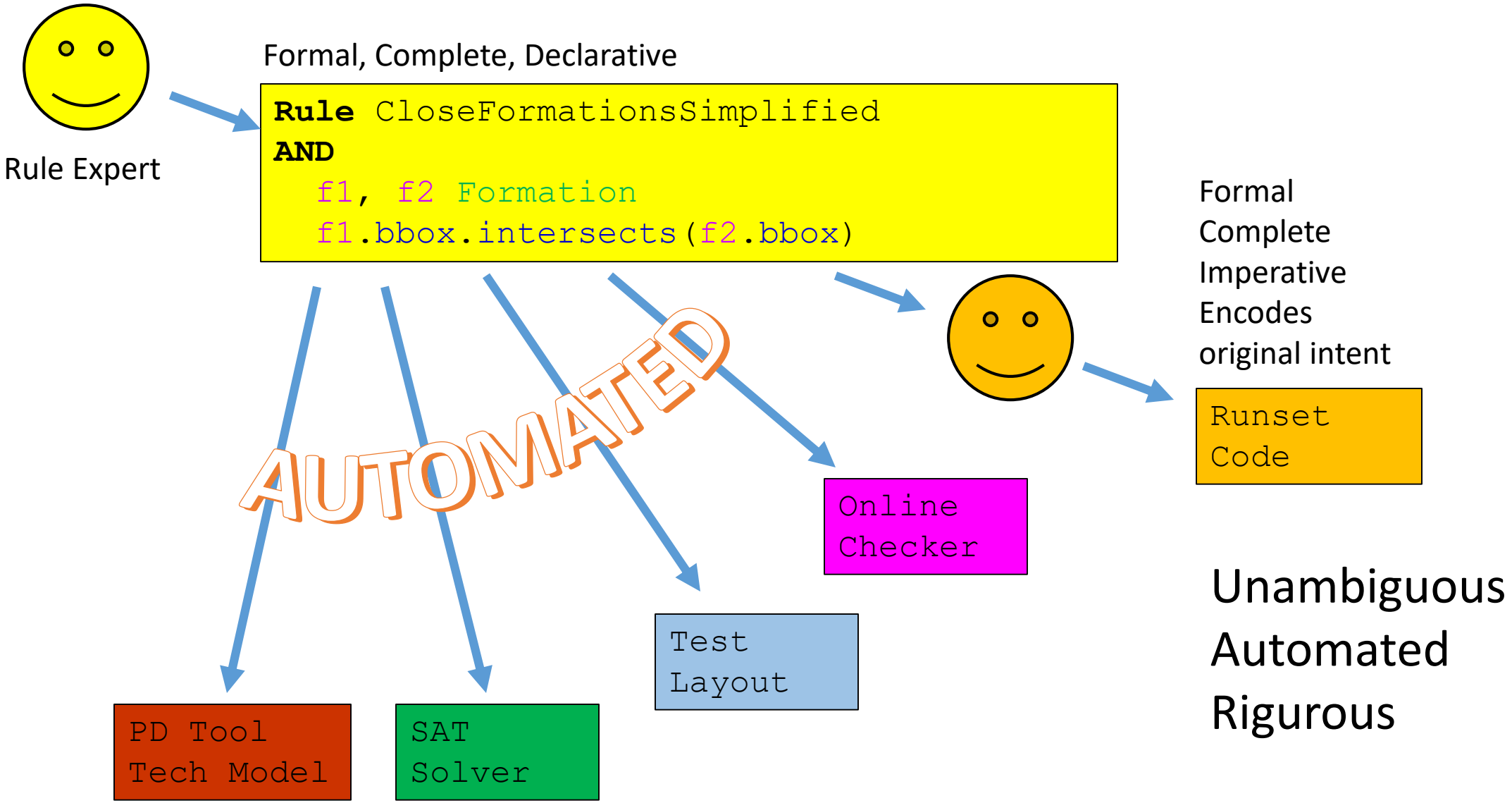
All these test layouts were automatically generated from the rule `CloseFormationsSimplified`, using mathematical solvers. The number of tests to be generated is an input parameter, can be in the thousands or higher.

Why?



Ambiguous
Labor intensive
Error-prone

Future, with the Declarative Language



Unambiguous
Automated
Rigurous

What

- A declarative language (think math, expressions, no state-change)
- Formal (computer readable)
- Compact, expressive
- Easy to teach, easy to write, easy to understand
- Support rules of any complexity, w/o need to modify language
- Aims to be the de-facto language for rule communication
  - Human to human, human to machine, machine to machine
- Expansive geometric function set
- Polygon Set support
- Advanced features: Patterns, Nested Patterns, Exceptions, Custom Functions, Grids, Sets, etc.

Status. Future Work.

- Language productized
- Online checker productized
- Automatic Test Layout Generator in Alpha release
- Automatic conversion to PD tool model – proof of concept
- Language open sourced to Si2 under OPAL name, older version

BACKUP

Actual layout used in unit testing patterns presented in this document