Beamfox

Beamfox Proximity

Write Field Import: YAML Format Specification

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Introduction

Write fields can be imported directly into Beamfox Proximity using a YAML file with a .yaml extension. This document explains the format used to generate write fields and aligment markers in such a file.

YAML Basics

At its core, files written in YAML primarily consist of key-value pairs, which in this documentation will be referred to as *statements*. Statements in YAML files contain an indentifier (the key) and the associated value, separated by a colon and space. Statements are separated by new lines. Some example statements are:

```yaml
company-name: "Beamfox Technologies"
pi: 3.14159
is-it-friday: true
```

In YAML, indentation is used to denote structure/nesting. YAML does not allow the use of tabs, and instead, spaces are used. There is no requirement to the number of spaces used to indent, as long as it is consistent throughout the document. In the example below, some properties of an `animal` is defined:

```yaml
animal:
   type: "Fox"
   legs: 4
   has-tail: true
```

Here, the statements `type`, `legs`, and `has-tail` "belong" to the `animal` statement due to their indentation. YAML supports values of primitive datatypes (integers, strings, etc.), but also more complex data structure objects. Such objects can in themselves be understood as collections of statements. In the example above, `animal` does not take a primitive datatype (e.g., an integer), but instead takes a data object that consists of the statements `type`, `legs`, `has-tail`, and possibly more. Some statements may be required or optional, depending on the type of object or other factors such as the inclusion of other statements.

YAML also supports lists, which are defined using hyphens, where a hyphen indicates a new element in the list. Expanding on the previous example:

```yaml
animal:
   type: "Fox"
   legs: 4
   has-tail: true
   diet:
      - "Rodents"
      - "Birds"
      - "Berries"
      - "Fruits"
```

This list with four elements is contained within the *diet* statement, which itself is contained within the *animal* statement.

YAML statement keys are case sensitive, while statement values that are strings, such as the values of `type` and the list members of `diet`, are not.

For more information about the YAML language, see https://en.wikipedia.org/wiki/YAML.

Creating write fields

To create write fields, the YAML file should contain a combination of *global* statements, *WriteField* statements, and others. The statement `fields`, detailed further below, contains a list of WriteField objects. New write fields (or write field lattices) can be created by adding WriteField objects to this list, which in YAML is done with hyphens. For example, a single write field of width 500 micrometers and 1 million dots, with center in (250, 250), can be created with:

```
size: 500
dots: 1000000
fields:
 - origin:
    x: 250
    y: 250
```

The `origin` statement is a required statement of the WriteField object and specifies the center coordinates of the write field. Note, that the `x` and `y` statements relate to the `origin` statement, and must therefore be nested within this statement.

Another write field with center in (750, 750) can be added by adding another WriteField object to the list:

```
size: 500
dots: 1000000
fields:
  - origin:
     x: 250
     y: 250
  - origin:
     x: 750
     y: 750
```

We can add further properties to each write field by adding further statements supported in the WriteField object. Expanding on the previous example, the size of the first write field size is here changed to 300 micrometers, and the pitch (beam step size) is changed to 2 in the second write field:

```
size: 500
dots: 1000000
fields:
  - origin:
     x: 250
     y: 250
    size: 300
  - origin:
     x: 750
     y: 750
    pitch: 2
```

Note that the indentation of these added statements must match the indentation level of the `origin` statement, as they are all WriteField statements that refer to the same WriteField object.

E-beam system compability

The YAML write field file is designed to be universal, and therefore independent of different e-beam systems, which may have different settings or feature sets. When loading a write field file into the Beamfox Proximity application and running proximity effect correction, the application will ensure that the specified write fields and their properties are compatible with the selected output file format. Therefore, if the YAML file contains statements and/or statement values that are not compatible with the selected output file format, these will be ignored or converted as best possible, or an error is produced.

For advanced users

The content in this section is not strictly necessary for understanding the basic functionality of the format, and can therefore be skipped at the readers discretion. It can, however, provide valuable insights for users with more advanced use cases.

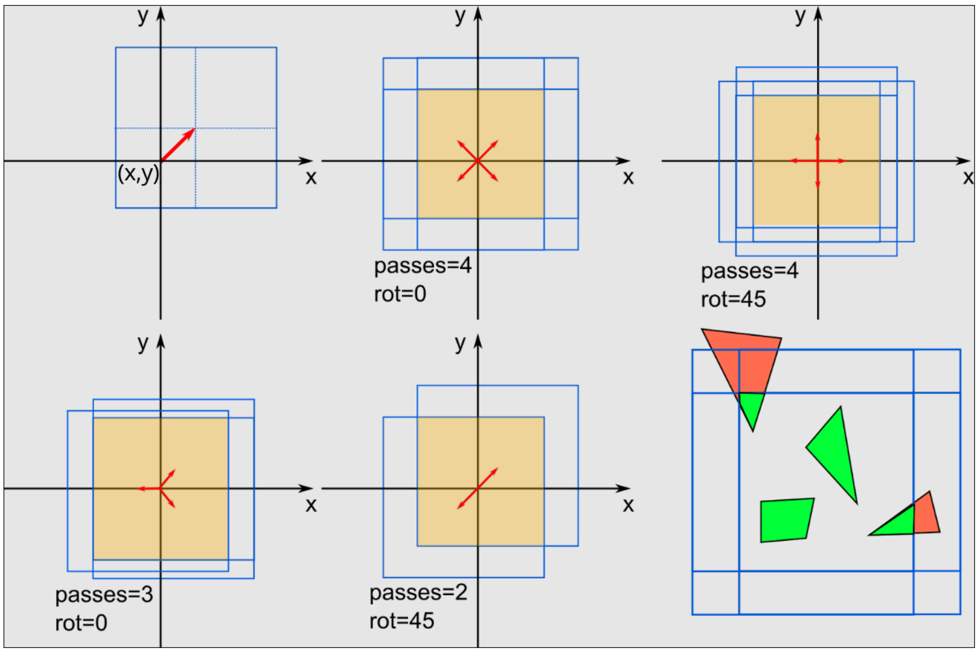
Virtual and physical write fields

It is possible to use write fields in Beamfox Proximity (virtual write fields) that are smaller than the actual write fields used by the e-beam system (physical write fields). This can potentially improve the quality and fidelty of the exposure, as this ensures writing will only occur in the central part of the physical write field, which reduces errors caused by defocus and astigmatism. The physical write field size is specified using the global `size` statement. The virtual write field size is specified using the `size` statement for individual WriteField objects.

Multi-pass mode

Geometries in the design that cross the interface between separate write fields are susceptible to stitching errors, caused by small offsets being introduced when the e-beam system moves from one write field to the next. This effect can be minimized at the expense of a slightly increased writing time by using multi-pass mode.

In multi-pass mode, geometries are written multiple times using a fraction of the dose with a slight offset each time. More specifically, the geometries are written `passes` number of times with a dose of 1 / `passes`. The offset between each pass is defined by a displacement distance of `shift`, and an angle of $\Phi_0 + \pi*(2n + 1)/N$ relative to the x-axis, where n is the pass id running from 0 to N - 1, Φ_0 = `rotation`, and N = `passes`.



Note: Beamfox Proximity will display the effective write field instead of all the individual multi-pass write fields. This results in a virtual write field that is smaller than the specified size.

Splitting of geometries into write fields

Before running proximity effect correction, Beamfox Proximity will first check for geometries that lie either fully or partially outside of any write fields. Geometries that are partially outside are split at the edge of the write field, after which all geometries that lie outside of any write fields are discarded.

During proximity effect correction, Beamfox Proximity will fracture all geometries based on dose, user settings, and existing fractures. The resulting geometries are then assigned to write fields.

The geometries will be assigned to the first write field in which the geometry can be entirely contained. The first write field depends on the writing order, which is determined by the order in the YAML file. For lattices, the order is defined by `write_mode`. If a geometry cannot be fully contained within a single write field, the geometry will be split at edge of the first write field. The two parts of the newly-split geometries are both considered new geometries, and go through the same process again. This process continues until all geometries have been assigned to write fields.

Autofill fields capture and split geometries similarly to write fields.

For write fields with multi-pass enabled, a geometry will only be captured by the resulting *effective* write field. In other words, a geometry will only be captured if it is placed within the area that is overlapped by all multi-pass passes.

Exposure errors can potentially be introduced when geometries are split between write fields. This effect can be minimized by introducing an `overlap` between write fields in a lattice, specified as a fraction of the write field `size`. This ensures that more geometries are completely contained within write fields and do not need to be split, at the cost of adding more write fields.

Global statements

Global statements are statements that are specified at the top level of the file. In other words, they are statements without indentation in the file. There are 4 overall types of global statements:

1. E-beam system setting statements. These are used to configure the e-beam system, and include the `size` and `dots` statements.
2. Write field value statements. These statements change the default properties of the write fields. If these values are not specified, the default values specified in this documentation are used. These statements can also be applied to individual write fields and write field lattices. Such statements include `pitch`, `multipass`, `overlap`, `write_mode`, and `origin_mode`.
3. Fields statement. Write fields are defined by adding elements to the `fields` statement.
4. Alignment marks. These statements describe the location of all global and local markers. This includes the `marks` and `local_marks` fields.

For statements that take either a scalar value or a point-like value, if a scalar value is provided, the value is converted to a point-like value with the same values for both x and y.

Statements

Name	Requirement	Value type	Conditions	Default	Description
`size`	Required	real or RealPoint	`size` > 0	-	The physical size of the write field in micrometers. All sizes of subsequently defined write fields must not be larger than this value. `size` must be a valid option in the e-beam system to be used.
`dots`	Required	integer or IntegerPoint	`dots` > 0	-	The number of dots for the write fields. `dots` must be a valid option in the e-beam system to be used.
`pitch`	Optional	integer or Pitch	`pitch` > 0	1	The default pitch for writing. This may be overridden for individual WriteField objects.
`multipass`	Optional	Multipass	-	disabled	The default multi-pass mode. This may be overwritten for individual WriteField objects. If not specified, multipass mode will be disabled.
`overlap`	Optional	real	0 <= `overlap` < 1	0	The default overlap for write field lattices. This may be overwritten for invidual WriteField objects.
`write_mode`	Optional	WriteMode	-	WriteMode::default	The default write mode for lattices and subfields. This may be overwritten for individual WriteField objects.
`origin_mode`	Optional	OriginMode	-	OriginMode::default	The default origin mode for lattices. This may be overwritten for individual WriteField objects.
`fields`	Optional	list of WriteField	-	empty	A list of WriteField objects each containing write fields or write field lattices. Write fields will be exported in the order of this list.
`marks`	Optional	list of RealPoint	-	empty	A list of the positions of all the global markers.
`local_marks`	Optional	list of RealPoint	-	empty	A list of the positions of all the local markers.

When loading a YAML write field file into the Beamfox Proximity application, the values specified in the file will overwrite the values set within the application.

See examples Marks.yaml, LocalMarks.yaml, and FullExample.yaml.

Global statements will in the following be referred to as global.statementName.

WriteField

The `global.fields` statement takes a list of WriteField objects, each of which describes a single write field or a lattice of write fields. If it is supplied, the `autofill` statement is used to create an autofill field that automatically places write fields within a given region.

Several of these statements can be used to overwrite the default values defined by global statements for the individual WriteField object.

Any WriteField object is technically a lattice of write fields, with the `columns` and `rows` specifying the number of columns and rows in the lattice. A single write field is a special case where both `columns` and `rows` are set to 1, or are both not given. By default, the lattice is arranged so that the write fields' edges touch. If the `overlap` statement is supplied, write fields in the lattice are arranged so that they overlap by the specified amount. Alternatively, the lattice vectors `lattice_vector_a` and `lattice_vector_b` can be given to specify the exact displacement between write fields in the lattice, where `lattice_vector_a` specifies the displacement between columns, and `lattice_vector_b` specifies the displacement between rows. It is recommended to use the `overlap` statement for most use cases, and only specify the lattice vectors for advanced use cases. Providing both the `overlap` statement and the lattice vector statements results in an error.

Statements

Name	Requirement	Value type	Conditions	Default	Description
`autofill`	Optional	AutoFill	-	disabled	If supplied, then creates a region to automatically place write fields. The AutoFill object then describes the information of the automatically filled region.
`origin`	Required*	Origin	-	-	The origin of the write field lattice/single write field.
`columns`	Optional*	integer	`columns` > 0	1	The number of columns in the lattice. Do not supply for a single write field.
`rows`	Optional*	integer	`rows` > 0	1	The number of rows in the lattice. Do not supply to get a single write field.
`lattice_vector_a`	Optional*	RealPoint	**	***	The primary lattice vector.
`lattice_vector_b`	Optional*	RealPoint	**	***	The secondary lattice vector.
`size`	Optional	real or RealPoint	0 < `size` <= `global.size`	`global.size`	The size of the write field(s).
`pitch`	Optional	integer or Pitch	`pitch` > 0	`global.pitch`	The pitch for writing.
`multipass`	Optional	false or Multipass	-	`global.multipass`	Enables multi-pass mode. If false, or not supplied, then multi-pass is disabled. The Multipass object then describes the multi-pass conditions.
`overlap`	Optional	real	0 <= `overlap` < 1	`global.overlap`	The overlap of the write fields in the lattice.
`write_mode`	Optional	WriteMode	-	`global.write_mode`	The write mode for the lattice and subfields for all write fields.

* Must not be supplied when `autofill` is enabled.
** `lattice_vector_a` and `lattice_vector_b` must not be parallel.
*** The lattice vectors default to vectors that ensure that specified `overlap` is fulfilled.

See examples FieldSingle.yaml, FieldDouble.yaml, FieldArray.yaml, FieldVectors.yaml, and FieldOverlap.yaml.

AutoFill

An autofill field describes a region in which the Beamfox Proximity application should automatically place write fields. Autofill fields capture geometries similarly to write fields, and after all geometries have been assigned, the autofill field is subsequently split into a write field lattice that consists of the smallest number of write fields that can cover the autofill field, respecting the specified values.

Autofill fields have no upper limit on their size, and can thus be larger than the physical write field `size`.

The AutoFill object describes the region covered by the autofill field, as well as the origin properties of the resulting write field lattice.

Geometries that lie outside of the AutoFill Regions and are not caputered by other write fields, will in all cases be discarded, even if the resulting write field lattice could contain them. When setting origin.mode.lattice to "LowerLeft", the origin should be placed at or before the lower left corner of the AutoFill Region. If the origin of the lattice is placed within the AutoFill Region, some geometries may be discarded.

Autofill areas are shown in the Beamfox Proximity application with a green tint to distinguish them from write fields.

Statements

Name	Requirement	Value type	Conditions	Default	Description
`origin`	Optional	Origin	-	disabled	The origin of the resulting lattice. This can be used to force the center or lower left side of the lattice to be at a specific location. If not supplied, the lattice will center on the contained geometries.
`region`	Optional	Region	-	disabled	The region from which geometries can be captured. If not supplied, then the entire plane is used as the region.

See examples AutofillDefault.yaml, AutofillRegion.yaml, and AutofillOrigin.yaml.

Origin

An Origin object is a point in the plane with real coordinates as well as an OriginMode that describes what part of the write field or write field lattice is located at that position.

Statements

Name	Requirement	Value type	Conditions	Default	Description
`x`	Required	real	-	-	The x-coordinate of the origin.
`y`	Required	real	-	-	The y-coordiante of the origin.
`mode`	Optional	OriginMode	-	`global.origin_mode`	The location within the write field lattice the origin point coordinates correspond to.

See example Origin.

Region

A Region object describes a rectangle in the plane.

Statements

Name	Requirement	Value type	Conditions	Default	Description
`size`	Required	real or RealPoint	`size` > 0	-	The size of the region.
`origin`	Required	RealPoint	-	-	The point in the plane where the origin is located.
`mode`	Optional	"LowerLeft" or "Center"	-	"LowerLeft"	What point in the region the `origin` point refers to.

See example Region.

RealPoint

A RealPoint object describes a point in the plane with real coordinates.

Statements

Name	Requirement	Value type	Conditions	Default	Description
`x`	Required	real	-	-	The x-coordinate of the point.
`y`	Required	real	-	-	The y-coordiante of the point.

See example RealPoint.

IntegerPoint

An IntegerPoint object describes a point in the plane with integer coordinates.

Statements

Name	Requirement	Value type	Conditions	Default	Description
`x`	Required	integer	-	-	The x-coordinate of the point.
`y`	Required	integer	-	-	The y-coordinate of the point.

See example IntegerPoint.

Pitch

A Pitch object describes the pitch (beam step size) used for writing. The pitch (beam step size) is the stride, or number of steps, between exposed dots. As an example, if the distance between dots is 0.5 nanometers, a specified pitch of 10 means that only every tenth dot is exposed, and the physical pitch becomes 5 nanometers. Note that scan and feed do not always correspond to the x and y (or, horizontal and vertical) directions, as this depends on the e-beam system and the geometry to write.

Statements

Name	Requirement	Value type	Conditions	Default	Description
`scan`	Required	integer	`scan` > 0	-	The pitch when scanning the geometry.
`feed`	Required	integer	`feed` > 0	-	The pitch when line feeding.

See example Pitch.

Multipass

The concept of multi-pass is detailed further up in this document, under *For advanced users - Multi-pass mode*.

Multi-pass is enabled when the `multipass` statement is given for a WriteField object. The Multipass object describes the properties of the multi-pass to be performed.

Statements

Name	Requirement	Value type	Conditions	Default	Description
`passes`	Required	integer	`passes` > 1	-	The number of write fields to use for multi-passing.
`shift_dist`	Required	real	`shift_dist` > 0	-	The distance to displace each write field.
`rotation_angle`	Optional	real	-	0	The offset angle of the displacement direction.

See example Multipass.yaml and MultipassDisabled.yaml.

WriteMode

The WriteMode object describes the writing mode, which itself determines the write order for write fields in lattices and subfields.

`dir` can be either "Horizontal" or "Vertical". In "Horizontal" mode, the write fields are written row by row. In "Vertical", mode the write fields are written column by column.

`type` can be either "Scan" or "Snake". In "Scan" mode, all rows/columns are written starting from the beginning of the row/column. In "Snake" mode, the rows/columns are written alternating from the beginning and the end of the row/column in a snake-like pattern.

Statements

Name	Requirement	Value type	Conditions	Default	Description
`dir`	Optional	"Horizontal" or "Vertical"	-	"Horizontal"	The direction to scan in while writing.
`type`	Optional	"Scan" or "Snake"	-	"Snake"	The mode for feeding to a new line.

See examples WriteModeHorizontalScan.yaml and WriteModeVerticalSnake.yaml.

OriginMode

When write field lattices are placed, the origin coordinates is given by the `origin` statement. However, what this position corresponds to within the field or lattice itself, is decribed by the OriginMode object.

The `lattice` statement describes the placement of `origin` within the lattice. If it is "Center", the specified origin position refers to the center of the lattice. If it is "LowerLeft", the specified origin position then refers to the location of the first write field in the lattice, the origin mode of which is determined by the `field` statement.

Statements

Name	Requirement	Value type	Conditions	Default	Description
`lattice`	Required	"LowerLeft" or "Center"	-	"LowerLeft"	The location of `origin` within the lattice.
`field`	Required*	"LowerLeft" or "Center"	-	"Center"	The location of `origin` within the origin write field.

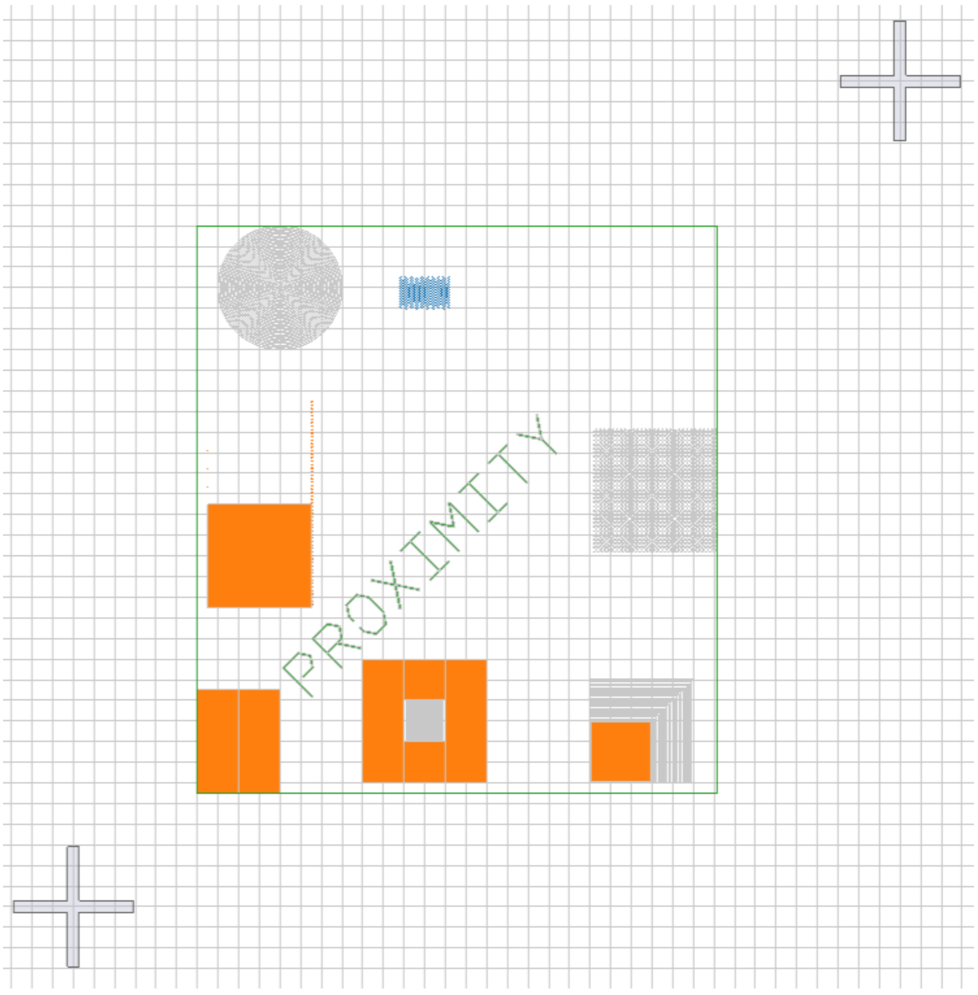
*Must not be supplied when `lattice` = "Center".

See examples OriginModeLL_LL.yaml, OriginModeLL_C.yaml, and OriginModeC.yaml.

Global statement examples

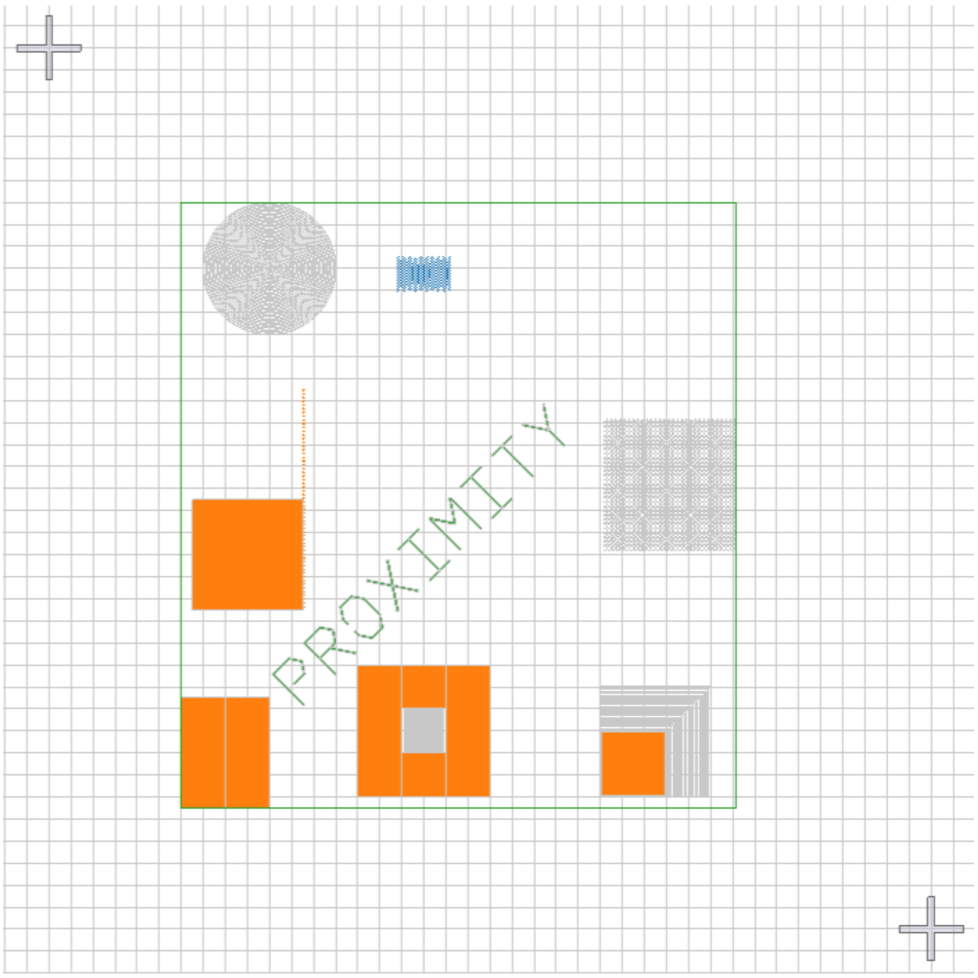
Marks.yaml

```yaml
size: 500
dots: 1000000
marks:
  - x: -50
    y: -50
  - x: 350
    y: 350
```



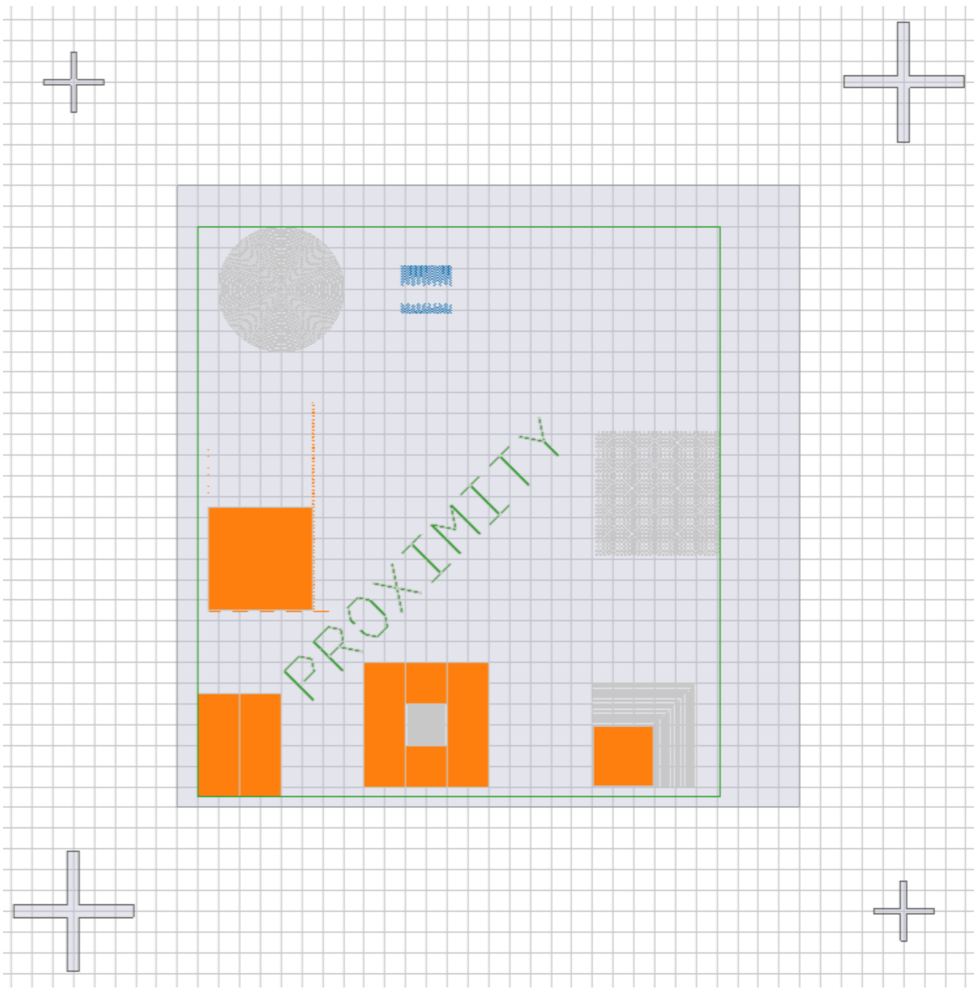
LocalMarks.yaml

```
size: 500
dots: 1000000
local_marks:
  - x: -50
    y: 350
  - x: 350
    y: -50
```



FullExample.yaml

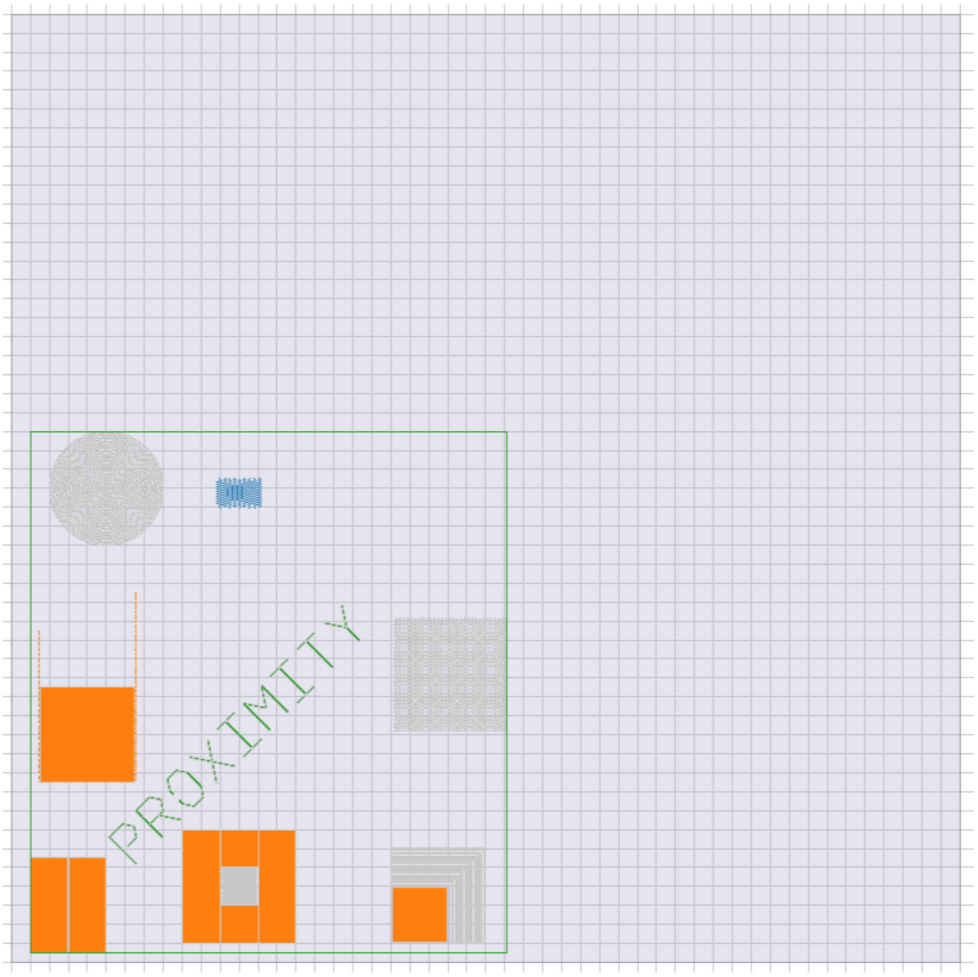
```yaml
size: 500
dots: 1000000
fields:
  - origin:
      x: 0
      y: 0
      mode:
        lattice: LowerLeft
        field: LowerLeft
    size: 300
marks:
  - x: -50
    y: -50
  - x: 350
    y: 350
local_marks:
  - x: -50
    y: 350
  - x: 350
    y: -50
```



WriteField examples

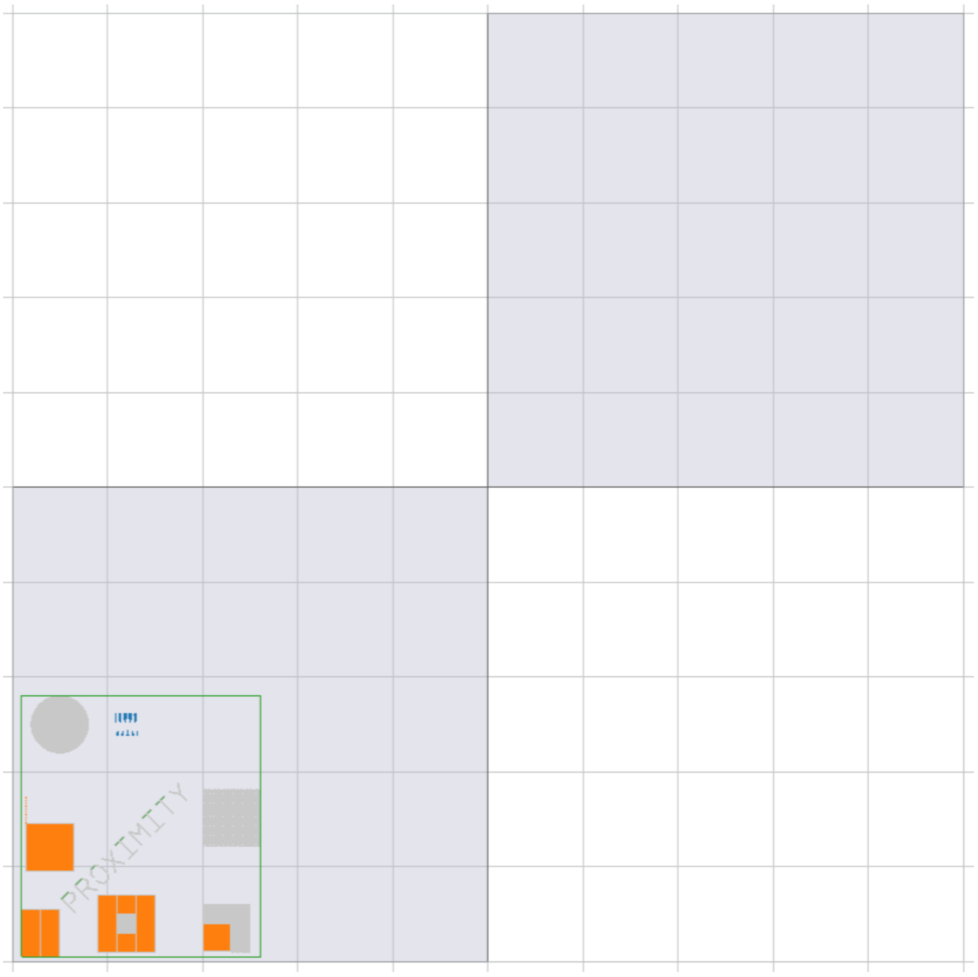
FieldSingle.yaml

```
size: 500
dots: 1000000
origin_mode:
  lattice: LowerLeft
  field: LowerLeft
fields:
  - origin:
      x: 0
      y: 0
```



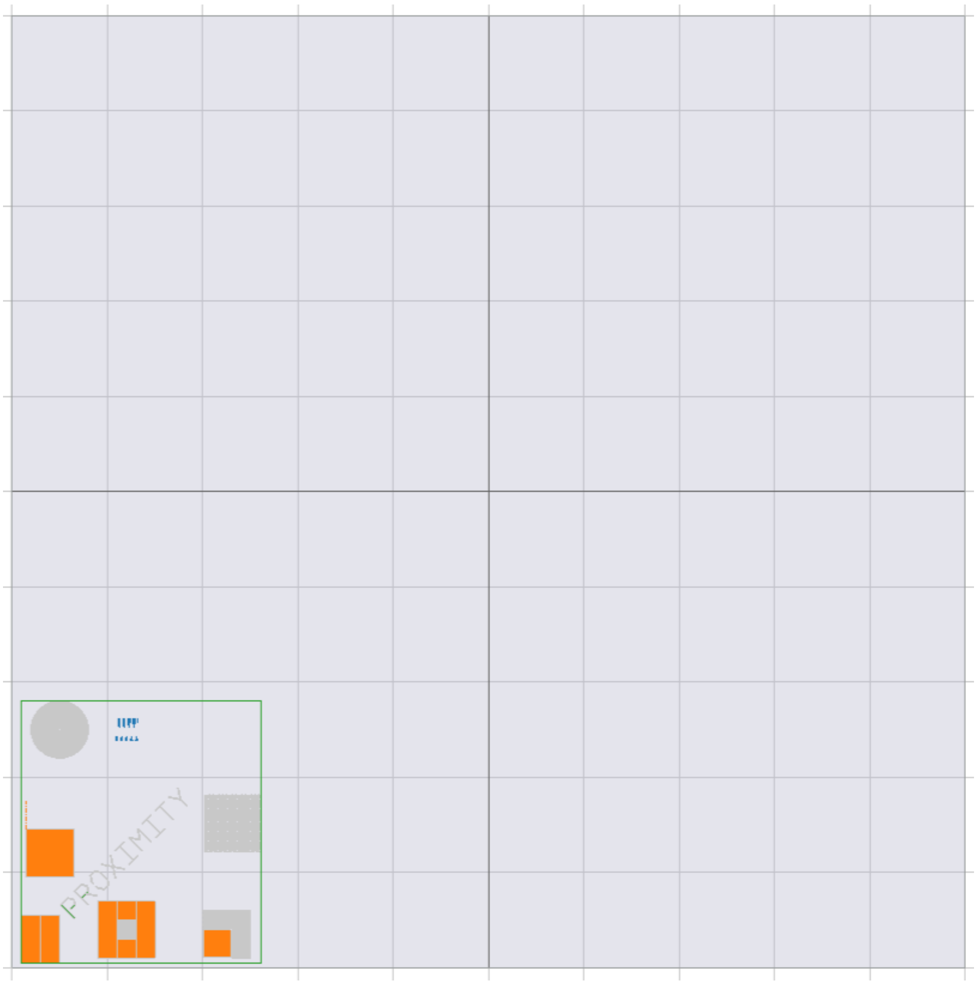
FieldDouble.yaml

```yaml
size: 500
dots: 1000000
origin_mode:
  lattice: LowerLeft
  field: LowerLeft
fields:
  - origin:
      x: 0
      y: 0
  - origin:
      x: 500
      y: 500
```



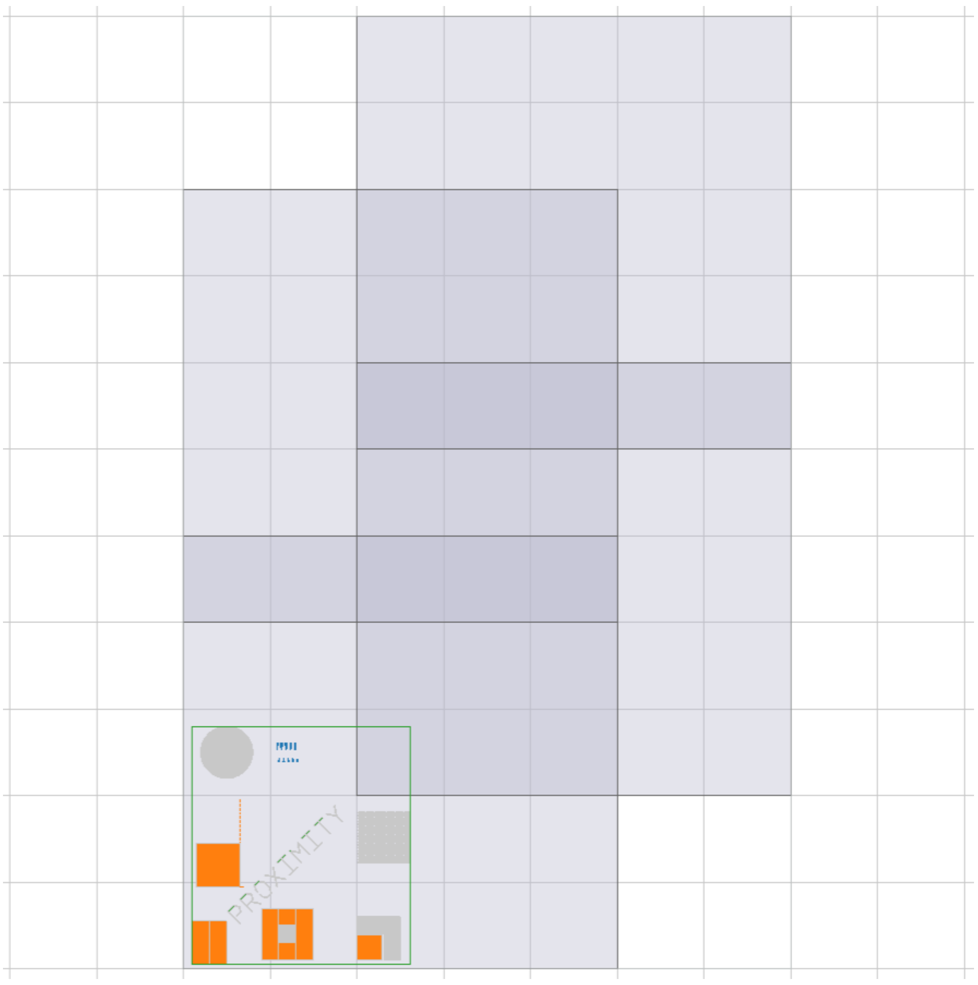
FieldArray.yaml

```yaml
size: 500
dots: 1000000
origin_mode:
  lattice: LowerLeft
  field: LowerLeft
fields:
  - origin:
      x: 0
      y: 0
    columns: 2
    rows: 2
```



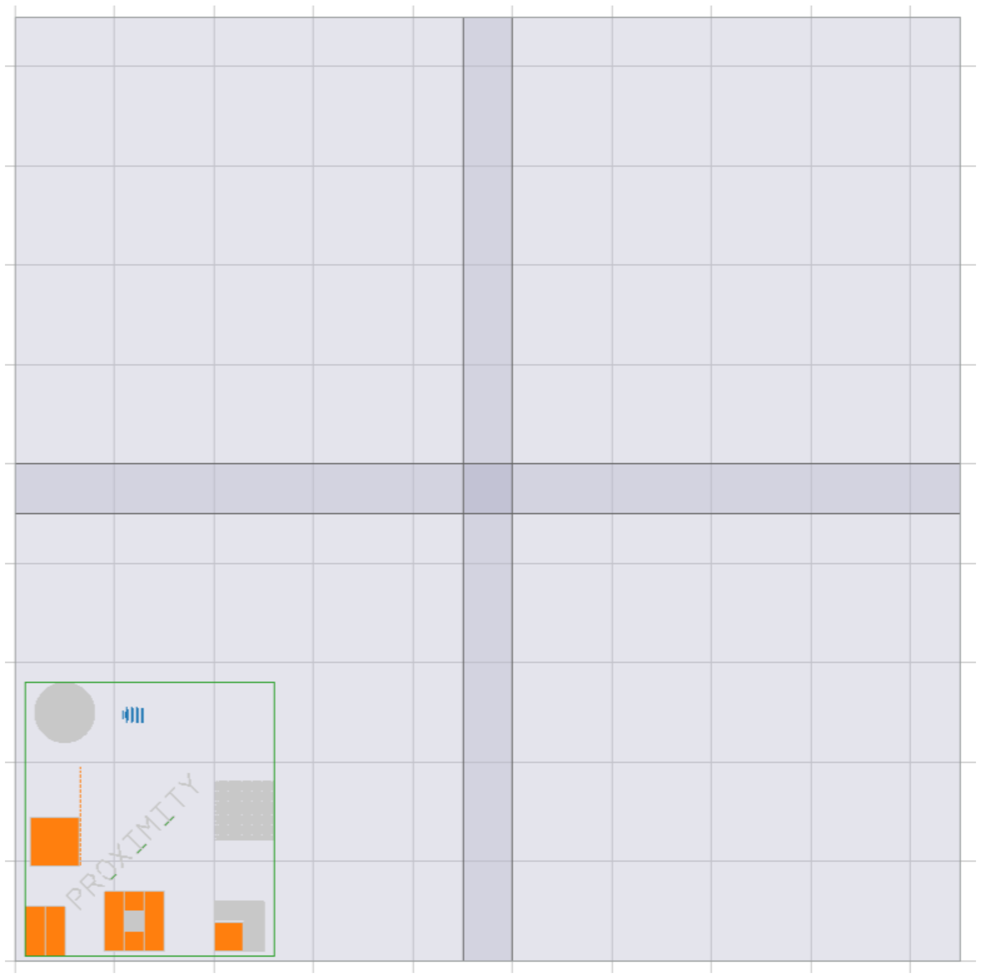
FieldVectors.yaml

```yaml
size: 500
dots: 1000000
origin_mode:
  lattice: LowerLeft
  field: LowerLeft
fields:
  - origin:
      x: 0
      y: 0
    columns: 2
    rows: 2
    lattice_vector_a:
      x: 200
      y: 200
    lattice_vector_b:
      x: 0
      y: 400
```



FieldOverlap.yaml

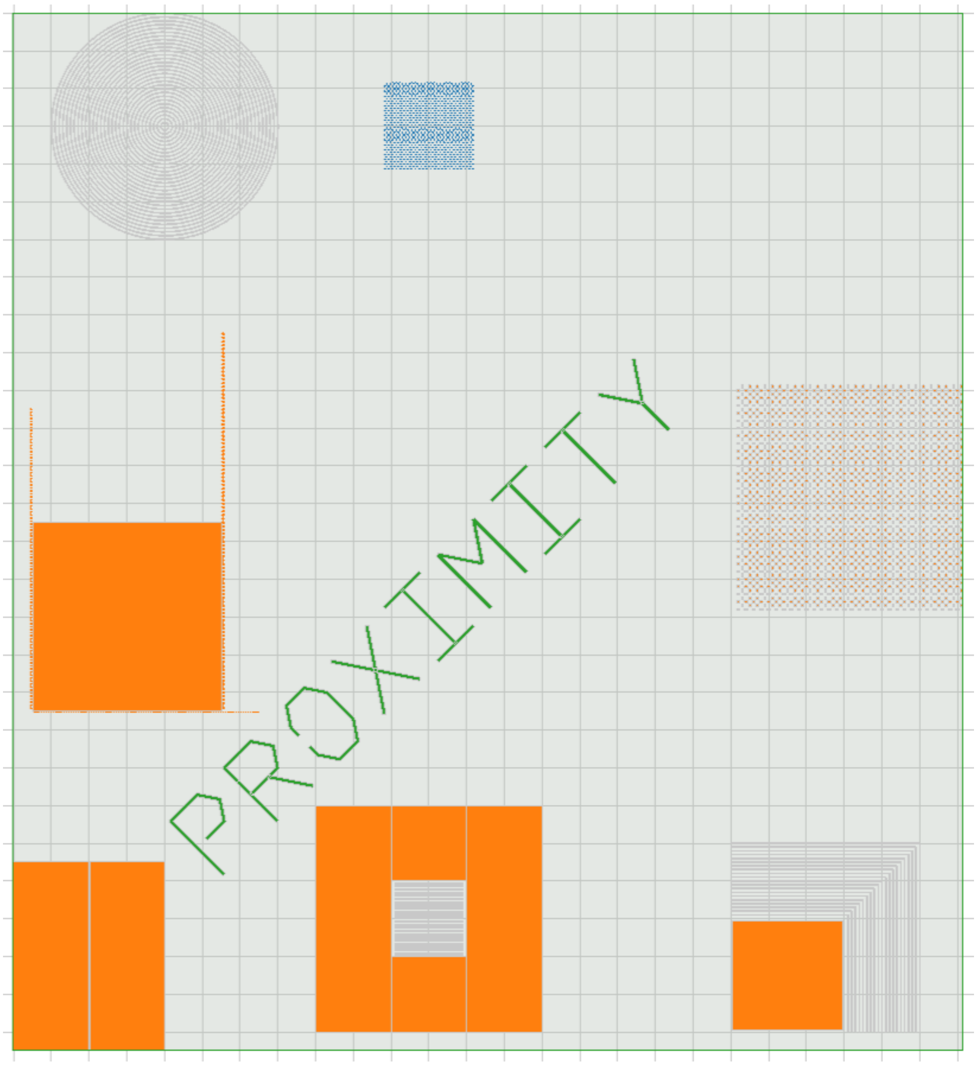
```yaml
size: 500
dots: 1000000
origin_mode:
  lattice: LowerLeft
  field: LowerLeft
fields:
  - origin:
      x: 0
      y: 0
    columns: 2
    rows: 2
    overlap: 0.1
```



AutoFill examples

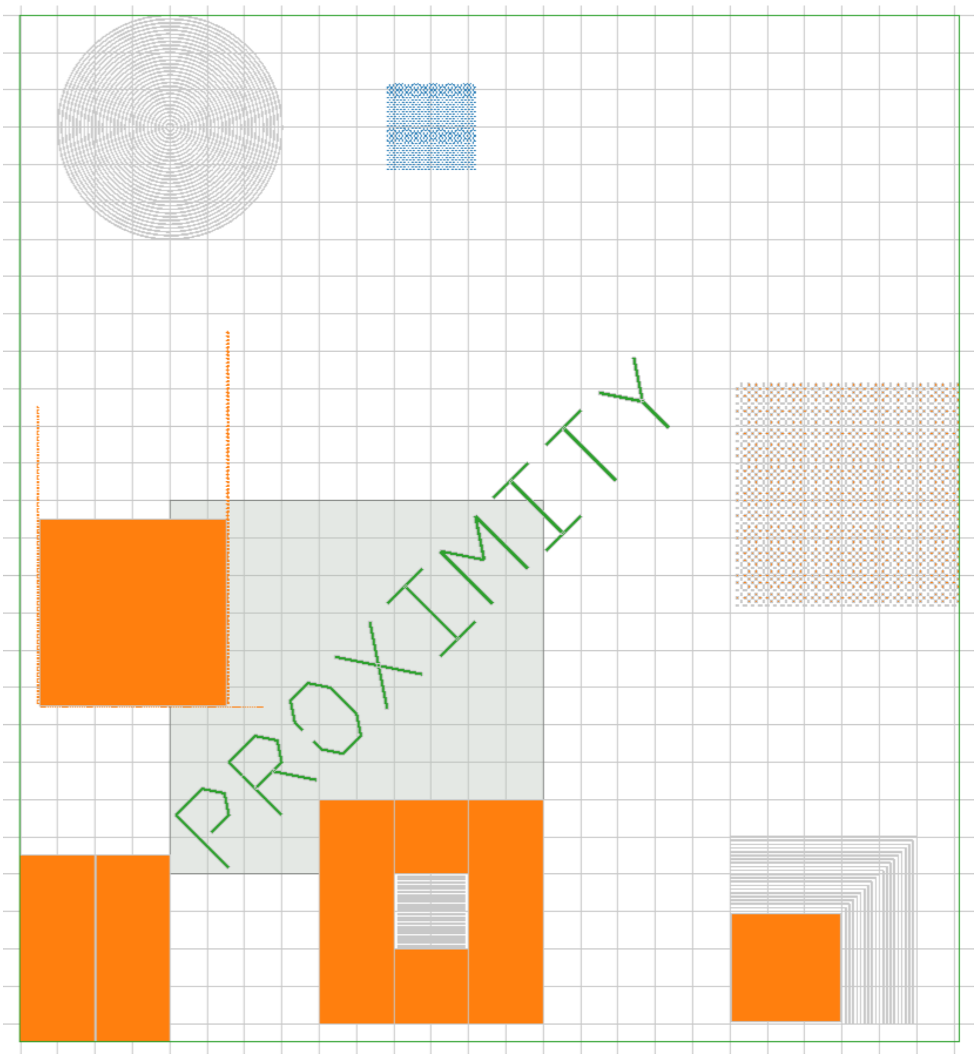
AutofillDefault.yaml

```yaml
size: 500
dots: 1000000
fields:
  - autofill:
```



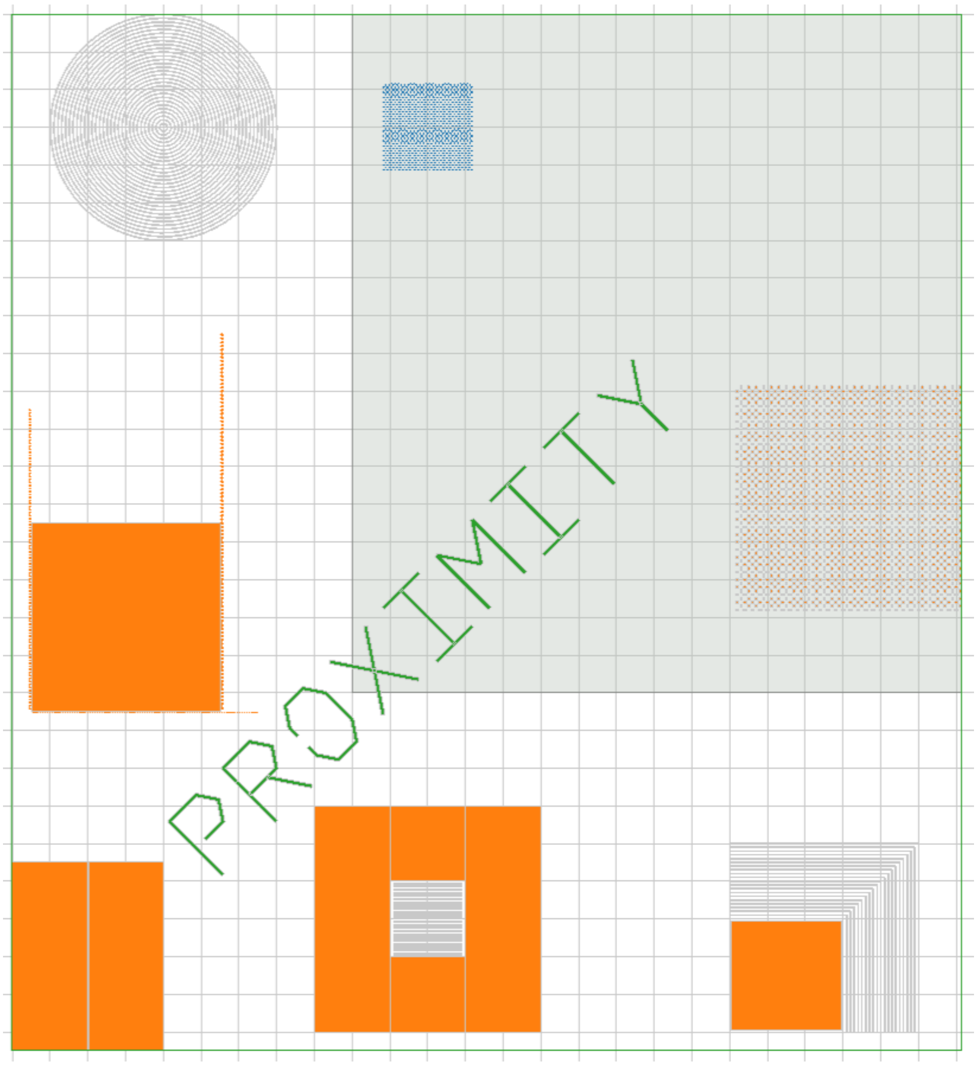
AutofillRegion.yaml

```yaml
size: 500
dots: 1000000
fields:
  - autofill:
      region:
        size: 100
        origin:
          x: 50
          y: 50
        mode: LowerLeft
```



AutofillOrigin.yaml

```yaml
size: 500
dots: 1000000
fields:
  - autofill:
      origin:
        x: 100
        y: 100
        mode:
          lattice: LowerLeft
          field: LowerLeft
```



Various examples

Origin

```
origin:
  x: 5.5
  y: 11.7
  mode:
    lattice: LowerLeft
    field: Center
```

Region

```
size: 1500
origin:
  x: 1000
  y: 500
mode: Center
```

RealPoint

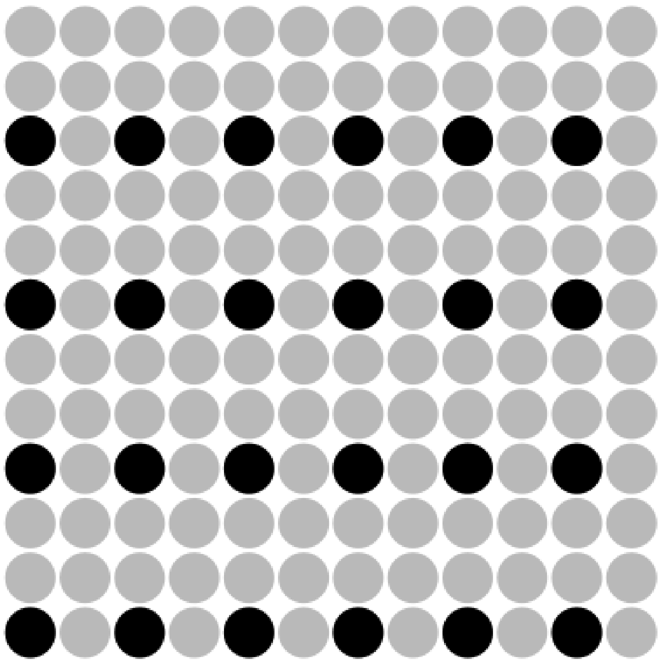
```
point:
  x: 6.2
  y: 1.6
```

IntegerPoint

```
point:
  x: 6
  y: 1
```

Pitch

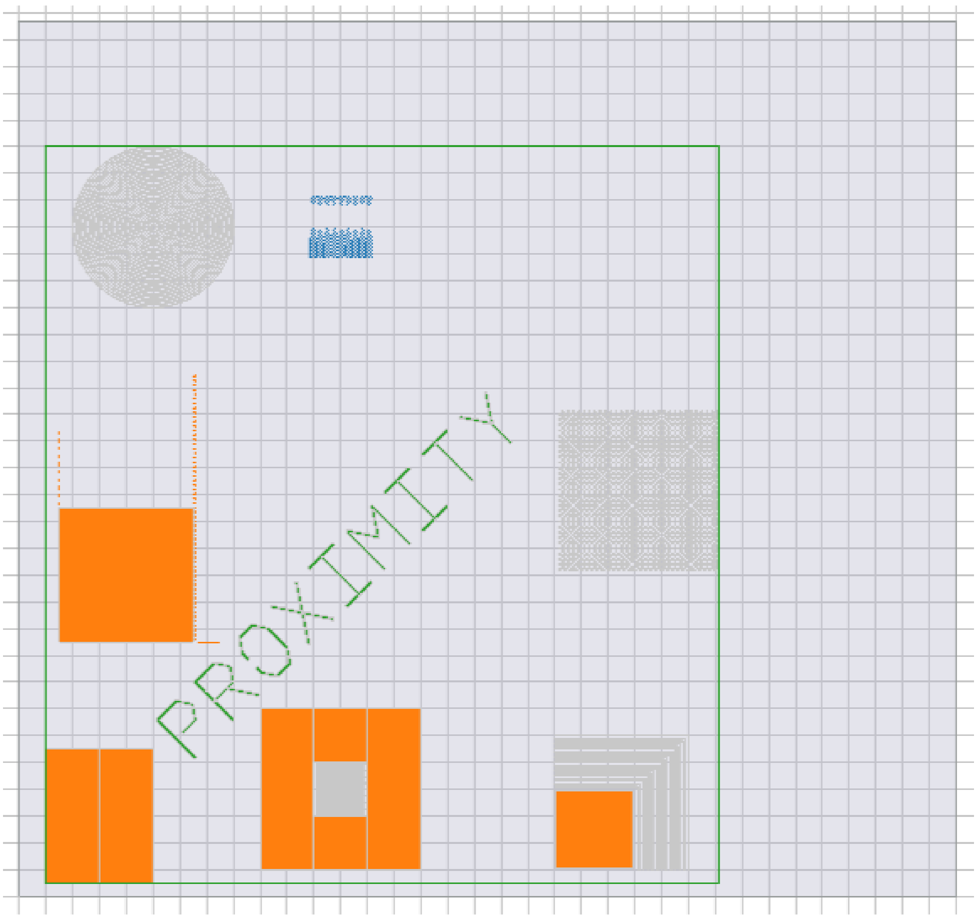
```
pitch:
  scan: 2
  feed: 3
```



Multipass examples

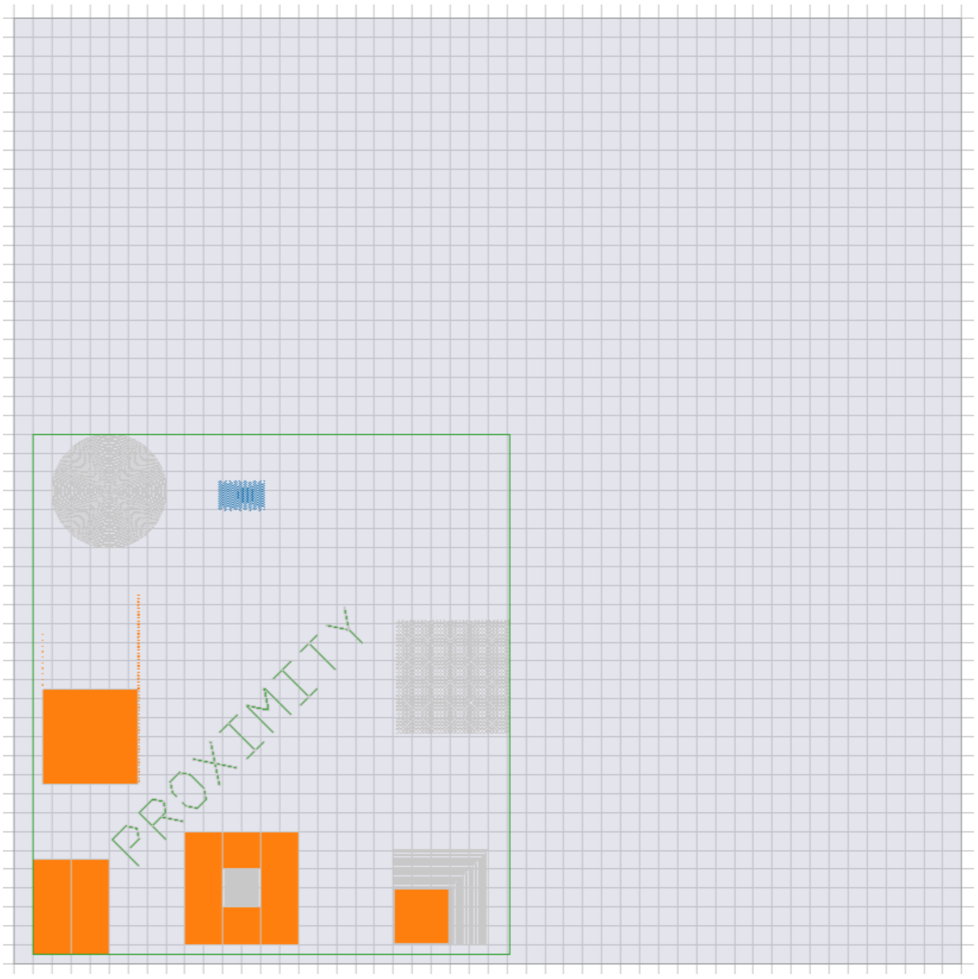
Multipass.yaml

```yaml
size: 500
dots: 1000000
multipass:
  passes: 3
  shift_dist: 100
  rotation_angle: -1.04719755119
fields:
  - origin:
      x: 0
      y: 0
      mode:
        lattice: LowerLeft
        field: LowerLeft
```



MultipassDisabled.yaml

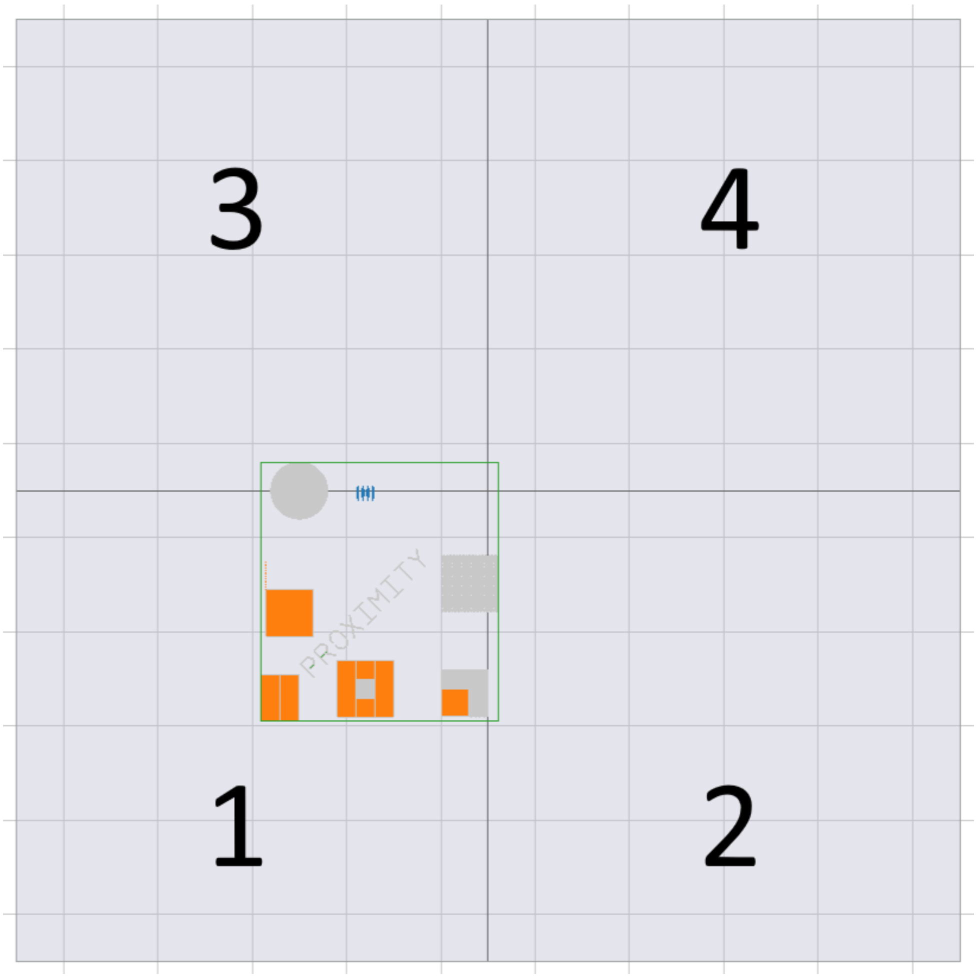
```
size: 500
dots: 1000000
multipass:
  passes: 3
  shift_dist: 100
  rotation_angle: -1.04719755119
fields:
  - origin:
      x: 0
      y: 0
      mode:
        lattice: LowerLeft
        field: LowerLeft
    multipass: false
```



WriteMode examples

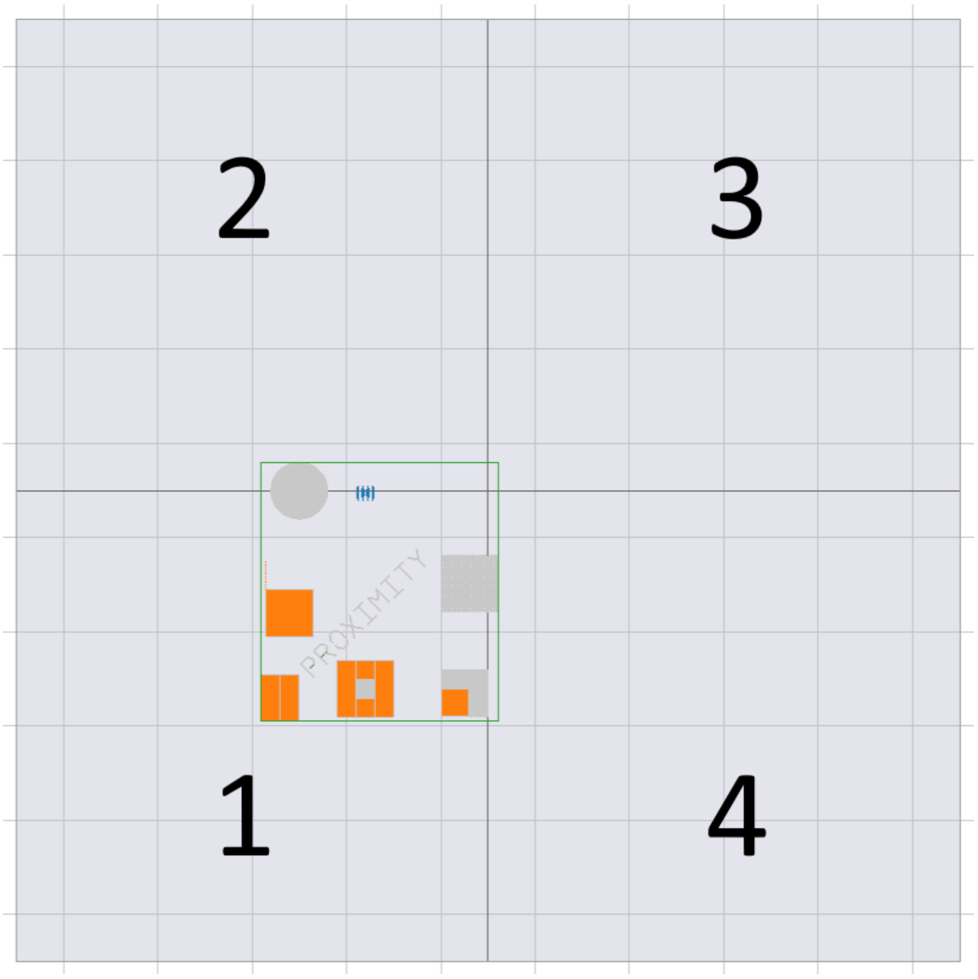
WriteModeHorizontalScan.yaml

```yaml
size: 500
dots: 1000000
write_mode:
  dir: Horizontal
  type: Scan
fields:
  - columns: 2
    rows: 2
    origin:
      x: 0
      y: 0
```



WriteModeVerticalSnake.yaml

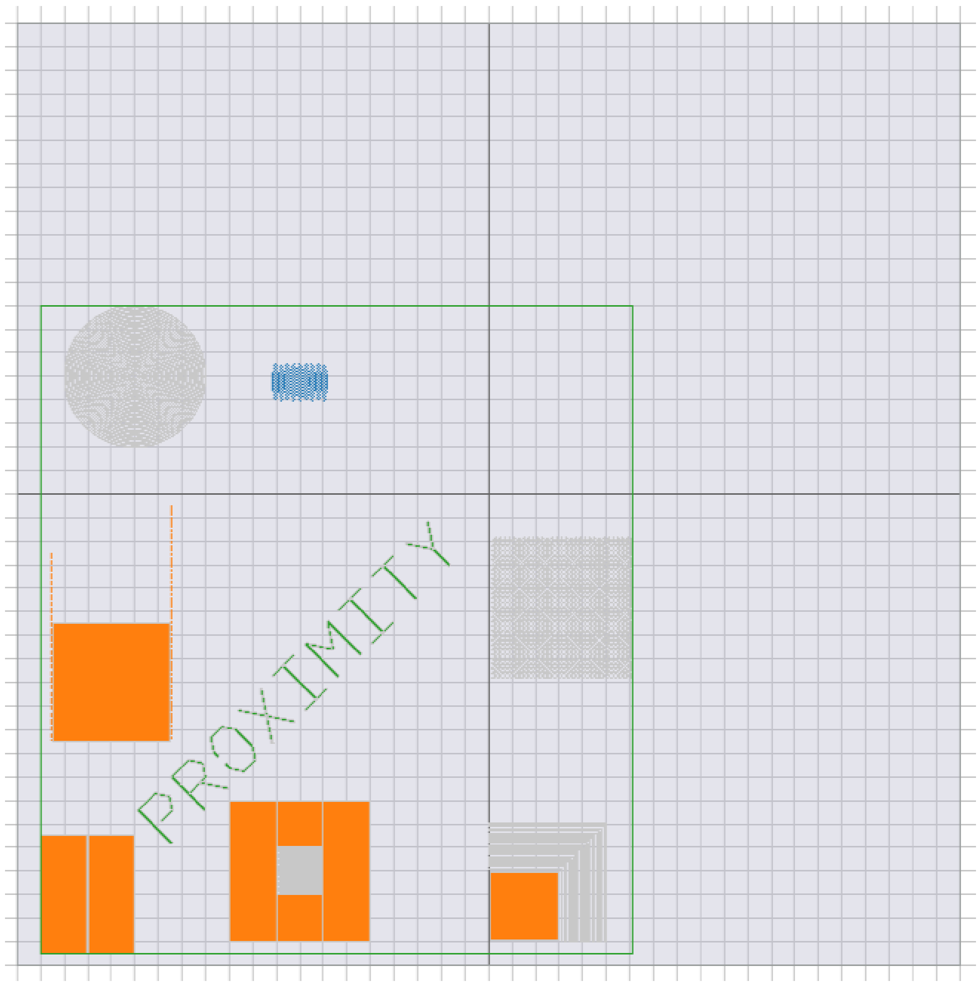
```yaml
size: 500
dots: 1000000
write_mode:
  dir: Vertical
  type: Snake
fields:
  - columns: 2
    rows: 2
    origin:
      x: 0
      y: 0
```



OriginMode examples

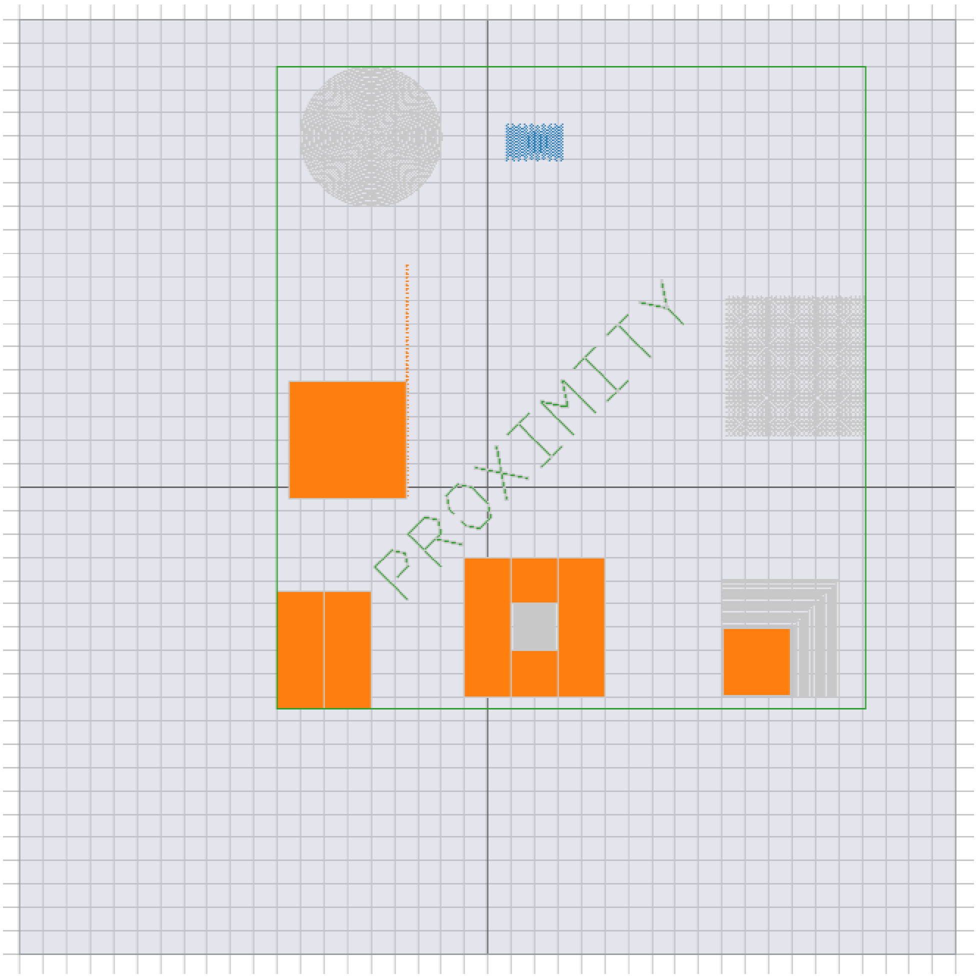
OriginModeLL_LL.yaml

```yaml
size: 500
dots: 1000000
origin_mode:
  lattice: LowerLeft
  field: LowerLeft
fields:
  - size: 200
    columns: 2
    rows: 2
    origin:
      x: 0
      y: 0
```



OriginModeLL_C.yaml

```
size: 500
dots: 1000000
origin_mode:
  lattice: LowerLeft
  field: Center
fields:
  - size: 200
    columns: 2
    rows: 2
    origin:
      x: 0
      y: 0
```



OriginModeC.yaml

```yaml
size: 500
dots: 1000000
origin_mode:
  lattice: Center
fields:
  - size: 200
    columns: 2
    rows: 2
    origin:
      x: 0
      y: 0
```