Signatures

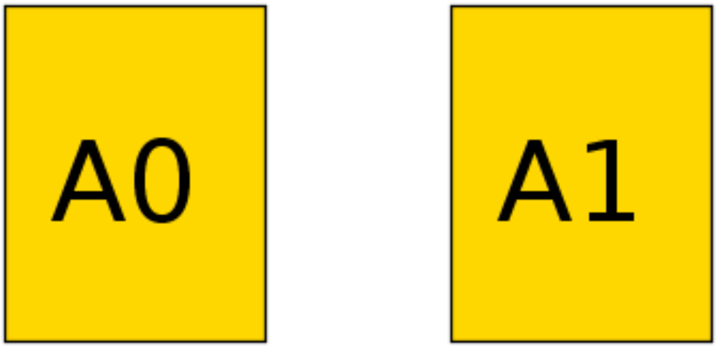
A **signature** expresses a new type in your spec. It can be anything you want. Here are some example signatures:

- Time
- State
- File
- Person
- Msg
- Pair

Alloy can generate models that have elements of each signature, called **atoms**. Take the following spec:

```
sig A {}
```

The following would be an example generated model:



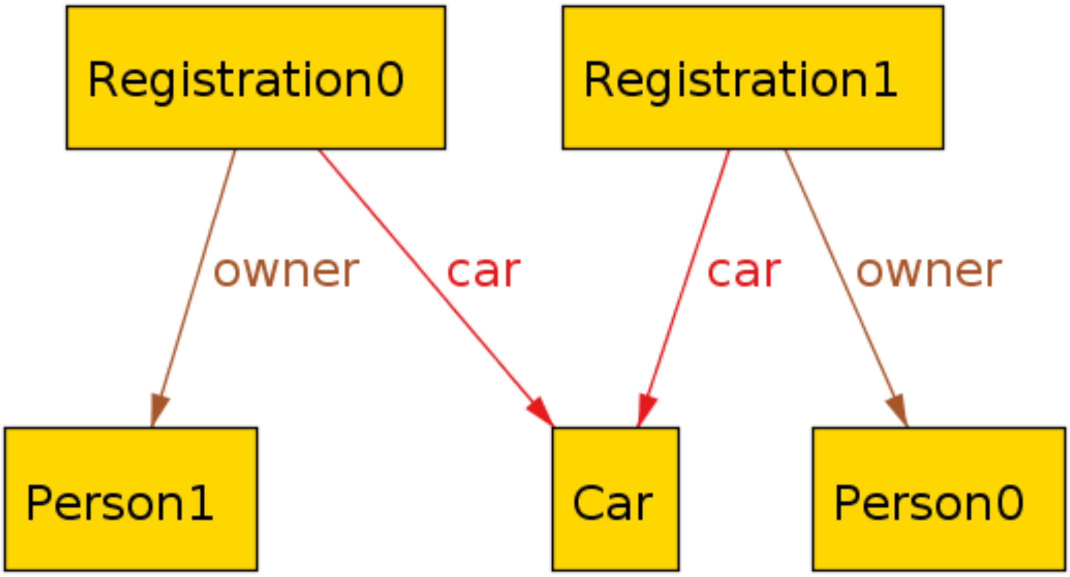
Here we have two atoms `A$1` and `A$0`. Both count as instances of the `A` signature. See visualizer for more on how to read the visualizations.

Usually we care about the relationships between the parts of our systems. We don't just care that there are people and cars, we care which people have which cars. We do this by adding **relations** inside of the signature body.

```
sig Person {}
sig Car {}

sig Registration {
  owner: Person,
  car: Car
}
```

This defines a new `Registration` type, where each Registration has an `owner`, which is a Person, and a `car`, which is a Car. The comma is required.



Tip

Extra commas are ignored. So you can write `Registration` instead like this:

```
sig Registration {
    , owner: Person
    , car: Car
}
```

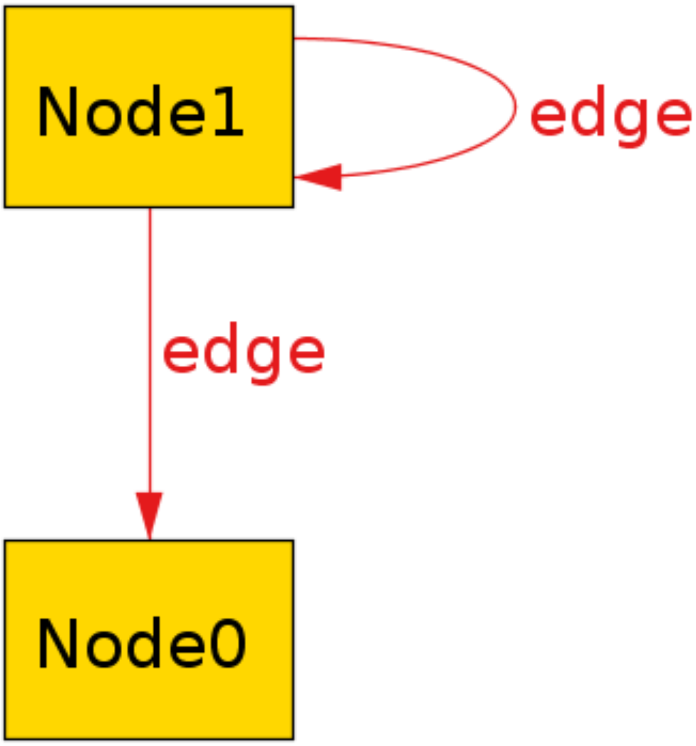
Relations

The body of a signature is a list of **relations**, which show how the signatures are connected to each other. A relation in the body of a signature is also called a **field**.

Relations are separated by a comma. The list can also start and end with a comma. Relations do not have to be on separate lines, as long as they are separated by commas.

Relations *can* refer to the same signature. This is valid:

```
sig Node {
    , edges: set Node
}
```



Alloy can generate models where a relation points from an atom to itself, aka a “self-loop”. For this reason we often want to add constraints to our model, such as Facts or Predicates.

Note

Each relation in the body of a signature actually represents a relation type. If we have:

```
sig A {r: one B}
```

Then `r` is set of relations in `A -> B`. See Sets and Relations for more information.

Different signatures *may* have relationships with the same name as long as the relationship is not ambiguous.

Multiplicity

Each relation has a **multiplicity**, which represents how many atoms it can include. If you do not include a multiplicity, it's assumed to be `one` for individual relations and `set` for Multirelations.

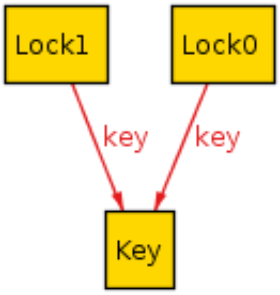
one

The default. `r: one A` states that there is *exactly one* A in the set.

```
sig Key {}

sig Lock {
  , key: one Key
}
```

This says that every lock has exactly one Key. This does *not* guarantee a 1-1 correspondence! Two locks can share the same key.



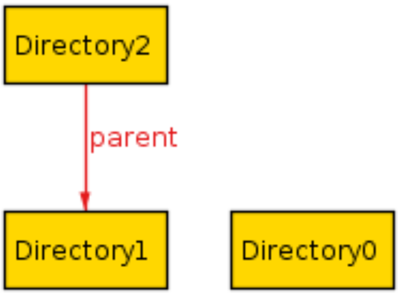
If no multiplicity is listed, Alloy assumes to be `one`. So the above relation can also be written as `key: Key`.

lone

`r: lone A` states that *either* there is one A in the set, *or* that the set is empty. You can also think of it as “optional”.

```
sig Directory {
  , parent: lone Directory
}
```

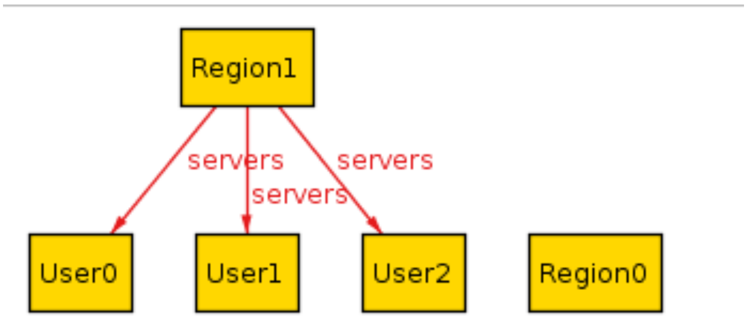
This says that every directory either has one parent, *or* it does not have a parent (it’s a root directory).



set

`r: set A` states that there can be any number of A in the relation.

```
sig User {}
sig Region {
  servers: set User
}
```

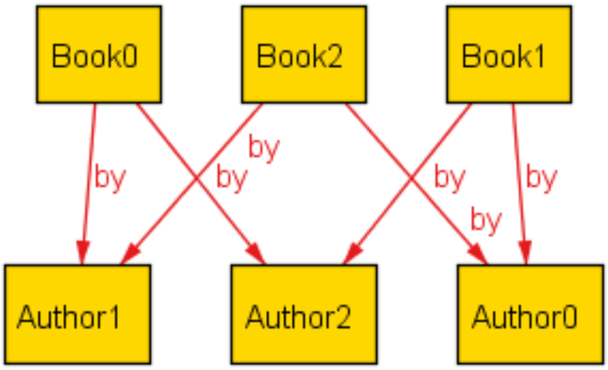


some

`r: some A` states that there is *at least one* A in the relation.

```
sig Author {}

sig Book {
  by: some Author
}
```



disj

`disj` can be prepended to any multiplicity to guarantee that it will be disjoint among all atoms. If we write

```
sig Lock {}
sig Key {
  lock: disj one Lock
}
```

Then every key will correspond to a *different* lock. If we instead write

```
sig Lock {}
sig Key {
  locks: disj some Lock
}
```

Then every key will correspond to one or more locks, but no two keys will share a lock.

seq

See here for more info.

Field Expressions

A field can be a simple expression over other signatures.

```
sig Resource {
  permissions: set (User + Group)
}
```

In addition to full signatures, the expression may contain `this`, which refers to the specific atom itself.

```
sig Node {
  -- no self loops
  , edges: set Node - this
}
```

A *dependent field* is one where the expression depends on the values of other fields in the atom. The dependencies must be fields defined either in the signature or its supertype.

```
sig Item {}

sig Person {
  , favorite: Item
  , second: Item - favorite
}
```

[⧗] Multirelations

Signatures can have multirelations as fields:

```
sig Door {}
sig Card {}

sig Person {
  access: Card -> Door
}
```

In this case `access` is a ternary relationship, where each element of `access` is a relation of form `Person -> Card -> Door`.

Multirelations have a special kind of multiplicity:

```
r: A m -> n B
```

This says that each member of `A` is mapped to `n` elements of B, and `m` elements of `A` map to each element of B. If not specified, the multiplicities are assumed to be `set`.

As an aid, use the following table:

m	n	Meaning

set	set	No restrictions
set	some	Each A used at least once
set	one	Each A is mapped to exactly one B (total function)
set	lone	Each A is mapped to at most one B (partial function)
some	set	Each B mapped to at least once
some	some	Every A mapped from and every B mapped to
some	one	Each A used exactly once, each B used at least once
some	lone	Each A used at most once, each B used at least once
one	set	Each B used exactly once, no other restrictions (one A can map to two
one	some	Each B used exactly once, each A used at least once
one	one	Only satisfiable if #A = #B, bijection
one	lone	At most #A arrows, exactly #B arrows, each A used at most once
lone	set	Each B used at most once
lone	some	Each A used at least once and each B used at most once
lone	one	Each A used exactly once, each B used at most once
lone	lone	Each A used at most once, each B used at most once

Not all multiplicities will have valid models. For example,

```
sig A {}
sig B {}
one sig C {
  r: A one -> one B
}

run {} for exactly 3 A, exactly 2 B
```

Since `r` must be 1-1, and there's different numbers of A and B sigs, nothing satisfies this model.

Multirelations can go higher than ternary using the same syntax, but this is generally not recommended.

Signature Multiplicity

In addition to having multiplicity relationships, we can put multiplicities on the signatures themselves.

```
one sig Foo {}
some sig Bar {}
//etc
```

By default, signatures have multiplicity `set`, and there may be zero or more in the model. By making the signature `one`, every model will have exactly one atom of that signature. By writing `some`, there will be at least one. By writing `lone`, there will be zero or one.

Subtypes

We can make some signatures subtypes of other signatures.

in

Writing `sig Child in Parent` creates an *inclusive* subtype: any Parent atoms may or may not also be a Child. This is also called a “subset subtype”.

```
sig Machine {}

sig Broken in Machine {}
sig Online in Machine {}
```

In this case, any Machine can also be Broken, Online, both, or neither.

[⧗] `+`

A single inclusive subtype can be defined for many parent signatures. We can do this by using the set union operator on the parent signatures.

```
sig Bill, Client {}

sig Closed in Bill + Client {}
```

extends

Writing `sig Child extends Parent` creates a subtype, as with `in`. Unlike `in`, though, any Parent atom can only match up to *one* extension.

```
sig Machine {}

sig Server extends Machine {}
sig Client extends Machine {}
```

In this case, any Machine can also be a Server, a Client, or neither, but not both.

Something can belong to both `extend` and `in` subtypes.

```
sig Machine {}
sig Broken in Machine {}

sig Server extends Machine {}
sig Client extends Machine {}
```

A Machine can be both a Server and Broken, or a Client and Broken, or just one of the three, or none at all.

abstract

If you make a signature `abstract`, then all atoms of the signature will belong to extensions. There will be no atoms that are just the supertype and not any of the subtypes.

```
abstract sig Machine {}
sig Broken in Machine {}

sig Server extends Machine {}
sig Client extends Machine {}
```

Here any machine **must** be either a Server or a Client. They still may or may not be Broken.

Warning

If there is nothing extending an abstract signature, the abstract is ignored.

Tip

You can place multiple signatures on the same line.

```
sig Server, Client extends Machine {}
```

Subtypes and Relationships

All subtypes are also their parent type. So if we have

```
sig B {}
sig C in B {}

sig A {
 , b: B
 , c: C
}
```

Then the `b` relation can map to atoms of `C`, and `c` cannot map to elements of `B` that are not also in `C`.

Tip

If you want to map to elements of `B` that are not also in `C`, you can write:

```
sig A {
  , b: B - C
}
```

[*] Child Relations

Children automatically inherit all of their Parent fields, *and also* can define their own fields. We can have:

```
sig Person {}
sig Account {
  , person: Person
}

sig PremiumAccount in Account {
  , billing: Person
}
```

Then all `Account` atoms will have the `person` field, while all will have both a `person` field and a `billing` field.

Note

This also applies to Implicit Facts. If Account has an implicit f applies to PremiumAccount.

It is not possible redefine a relationship, only to add additional

[*] Enums

Enums are a special signature.

```
enum Time {Morning, Noon, Night}
```

The enum will always have the defined atoms in it. Additionally, the atom will have an `ordering`. In this case, Morning will be the first element, Noon the second, and Night will be the third. You can use enums in facts and predicates, but you cannot add additional properties to them.

Tip

If you want to use an enumeration with properties, you can emulate this by using `one` and signature extensions.

```
abstract sig Time {}

one sig Morning, Noon, Night extends Time {
    time: Time
}
```

You can also use this to make enumerations without a fixed number of elements, by using `lone` instead.

Warning

Each enum implicitly imports `ordering`. The following is invalid:

```
enum A {a}

enum B {b}

run {some first}
```

As it is ambiguous whether `first` should return `a` or `b`. If you need to use both an enum inside of a dynamic model, be sure to use a namespace when importing `ordering`.