Move operations and rvalue references

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Motivation: unnecessary copies in C++03

Met Office

In C++03, appending to a full vector causes a lot of copy operations.

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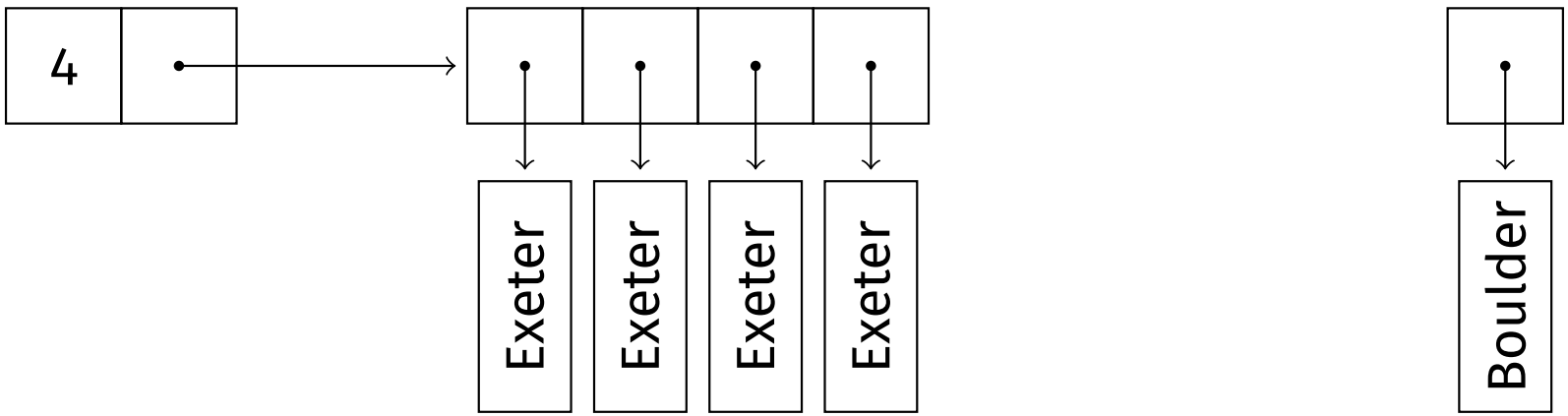

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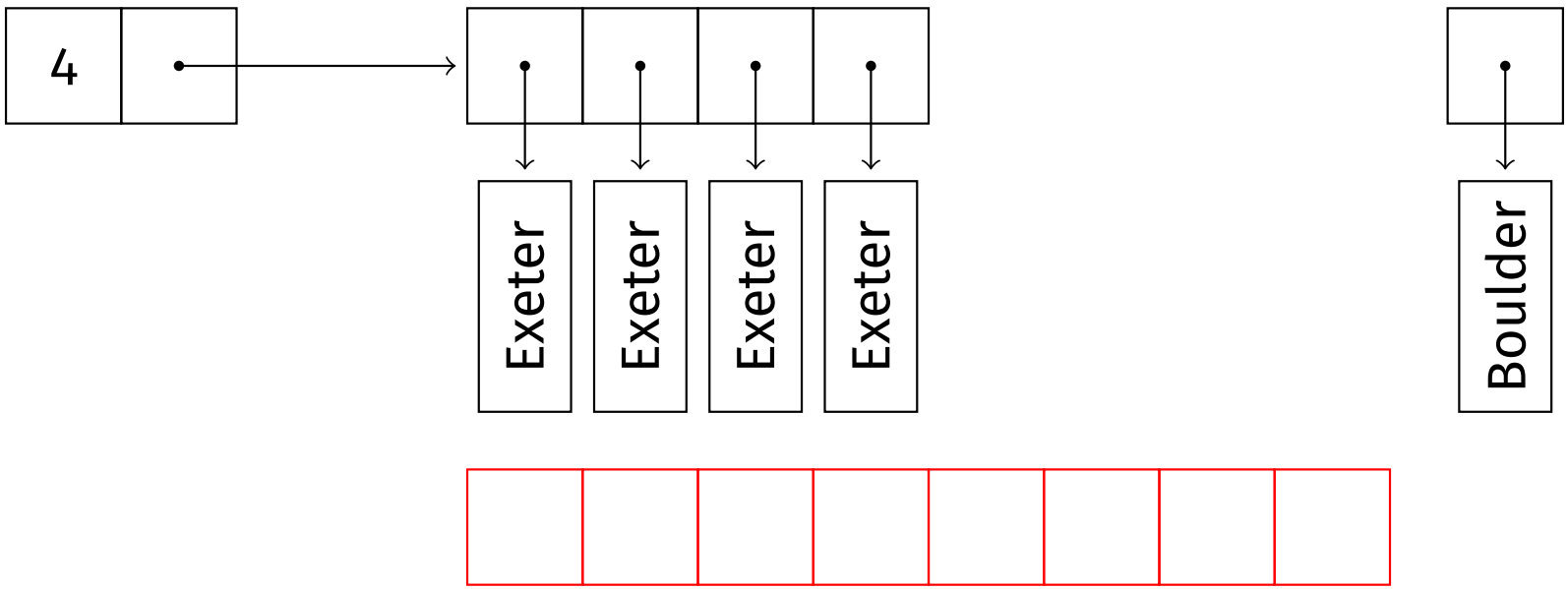

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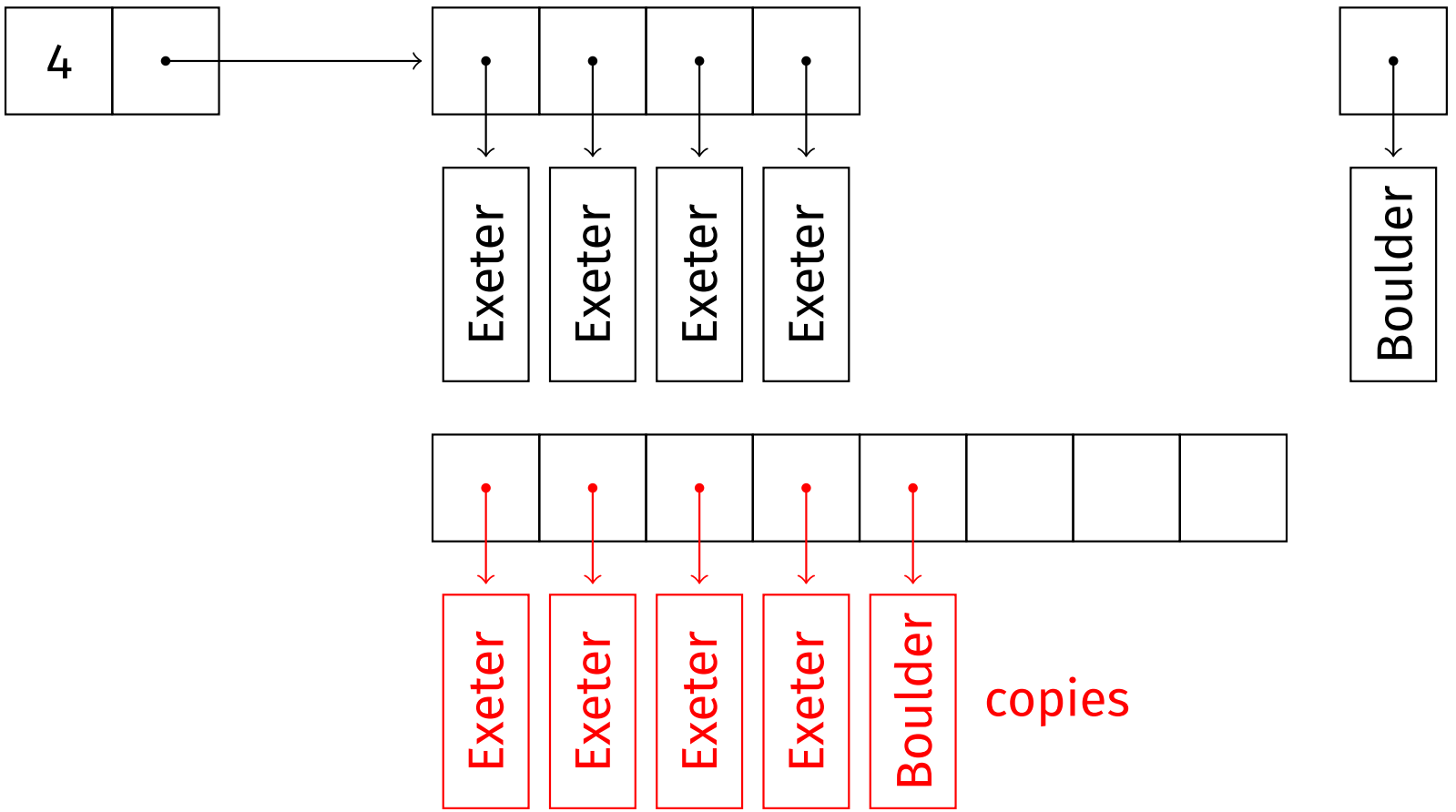

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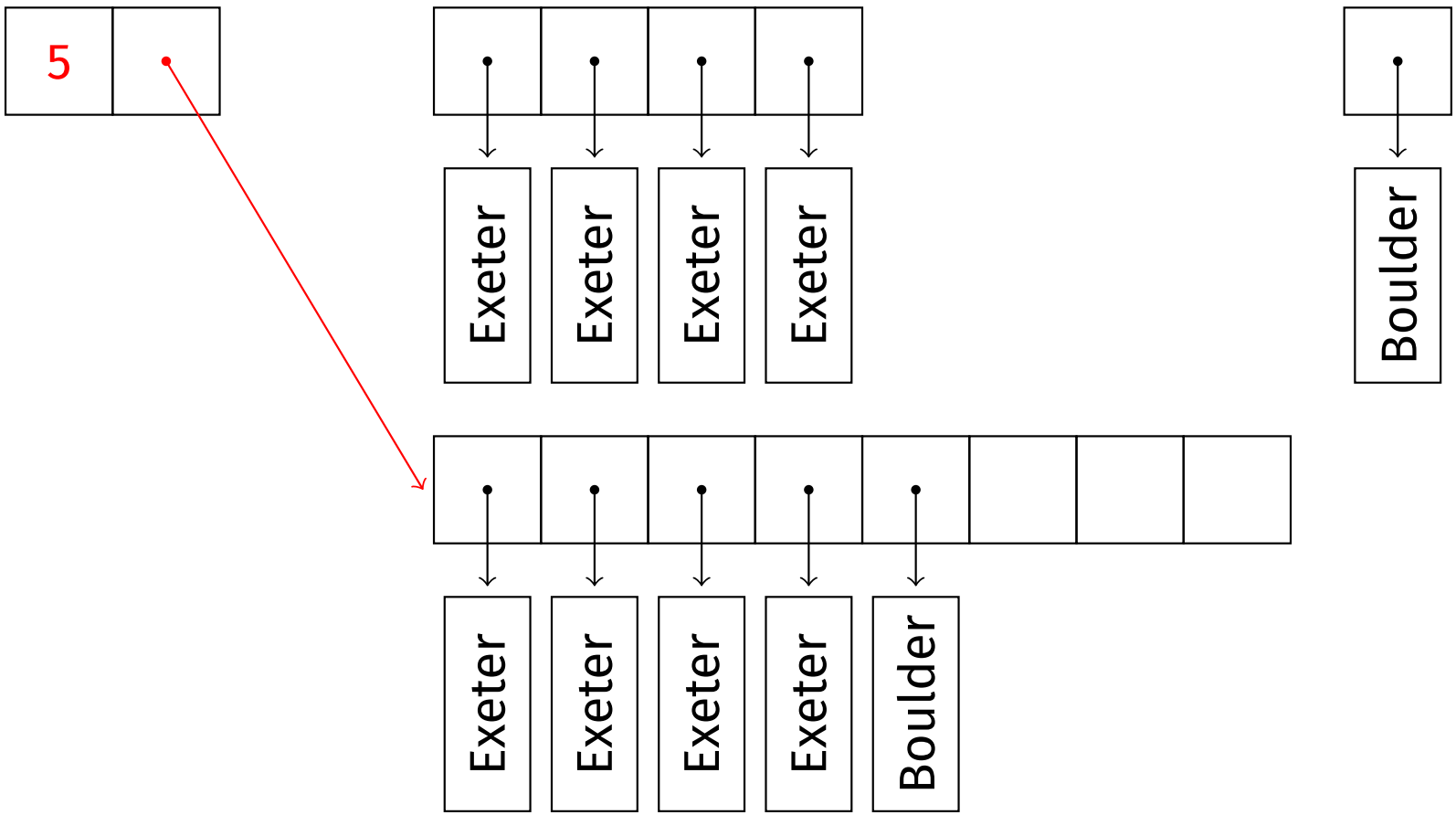

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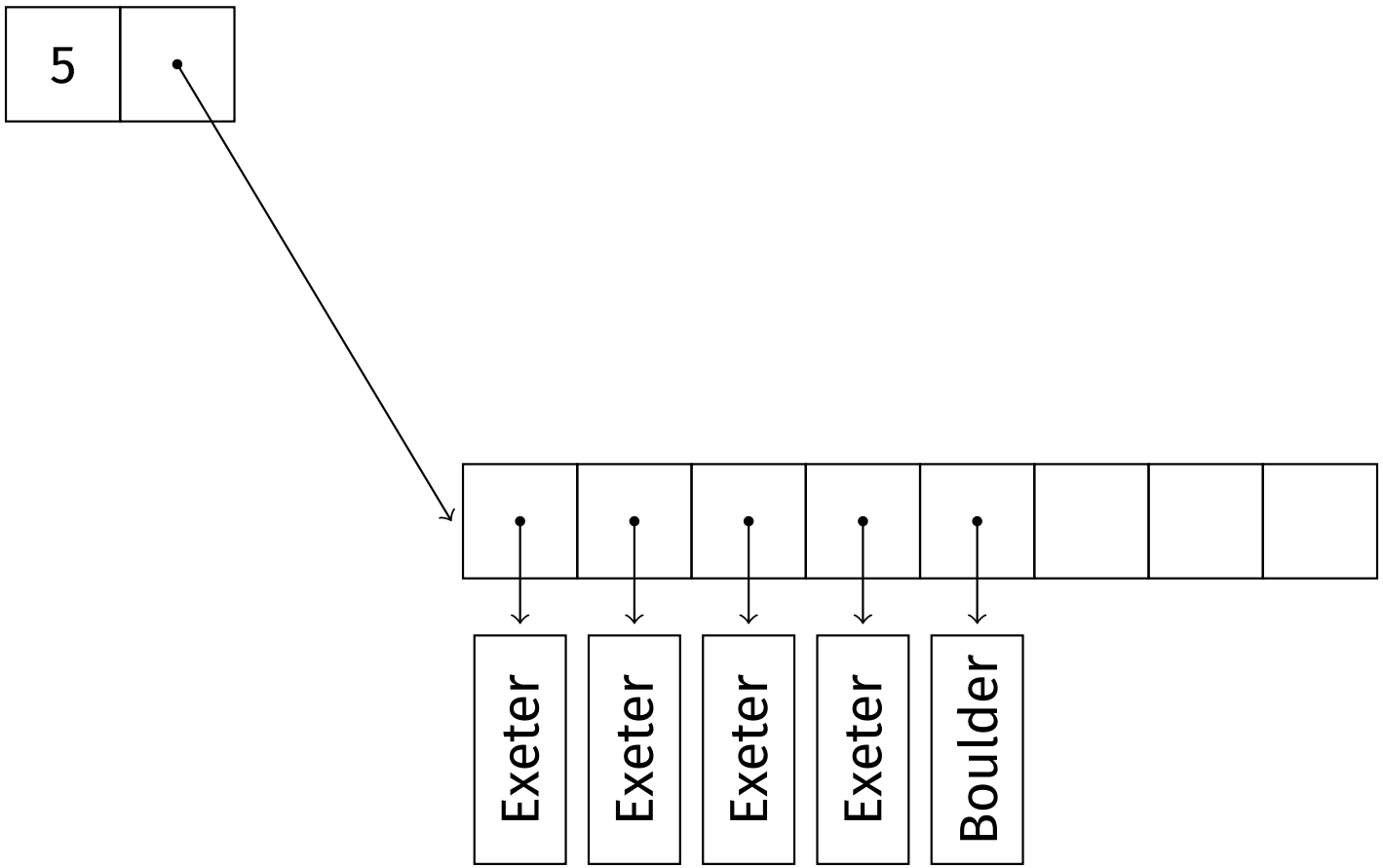

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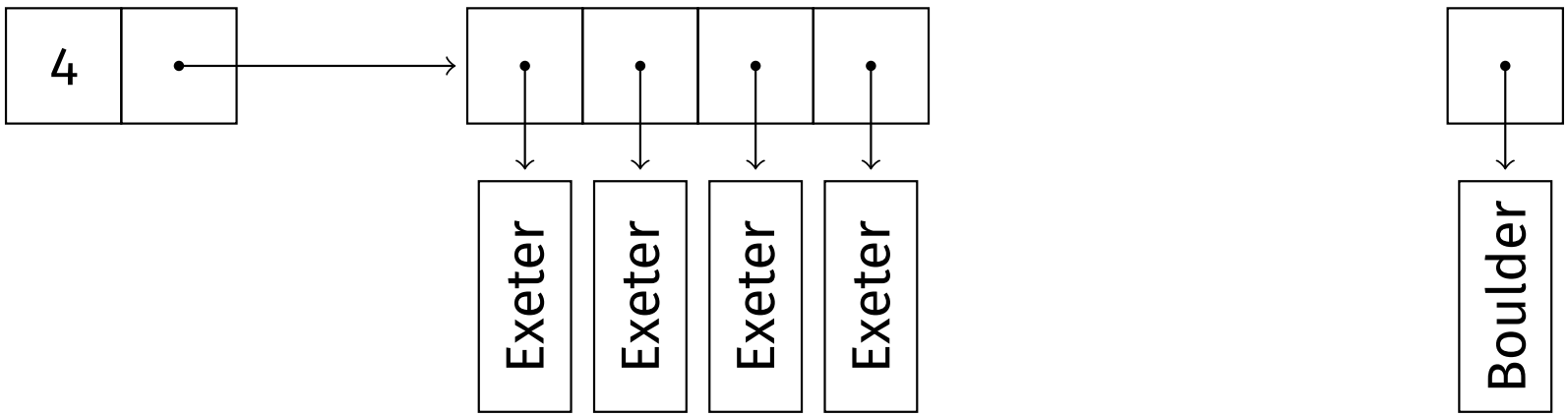

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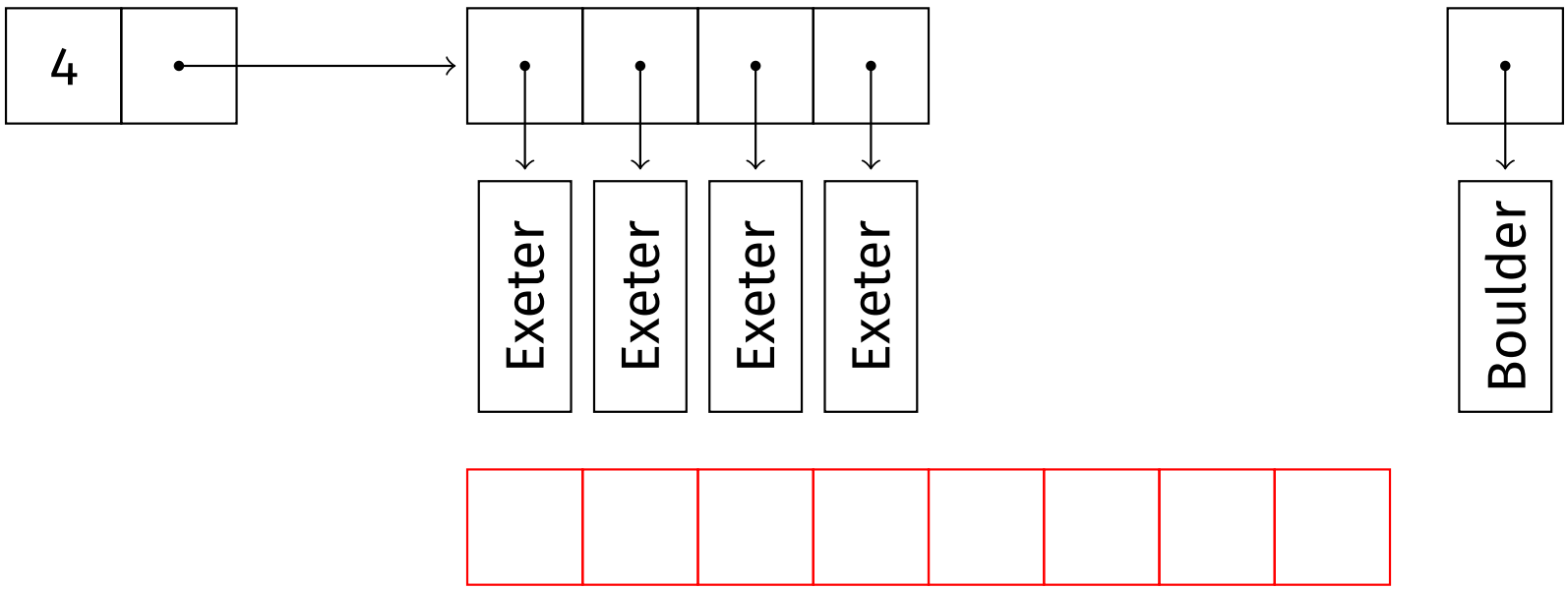

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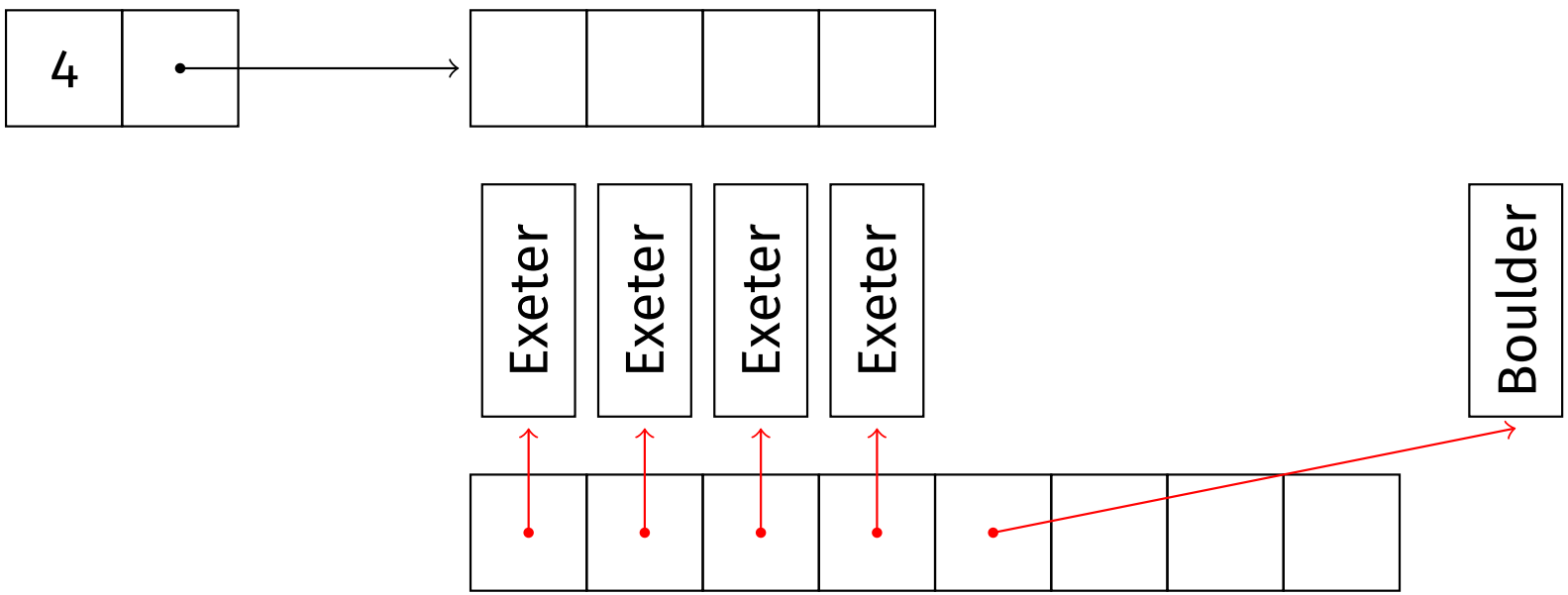

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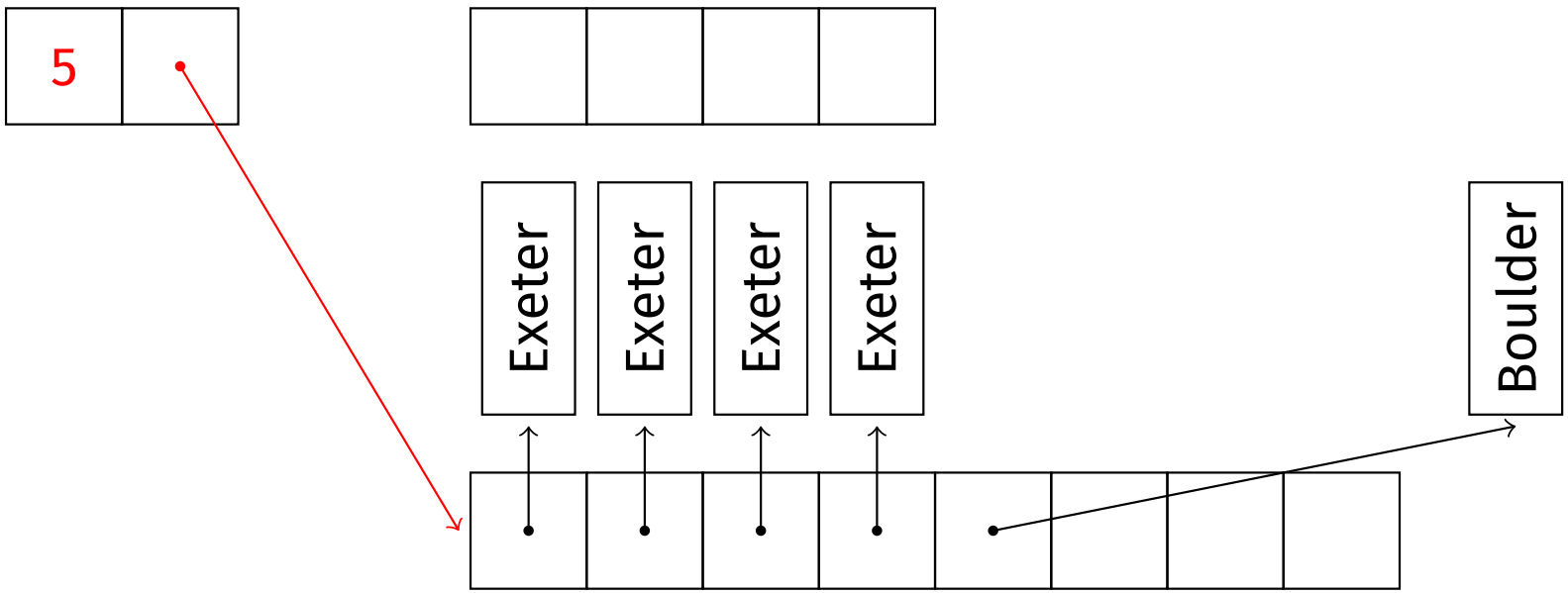

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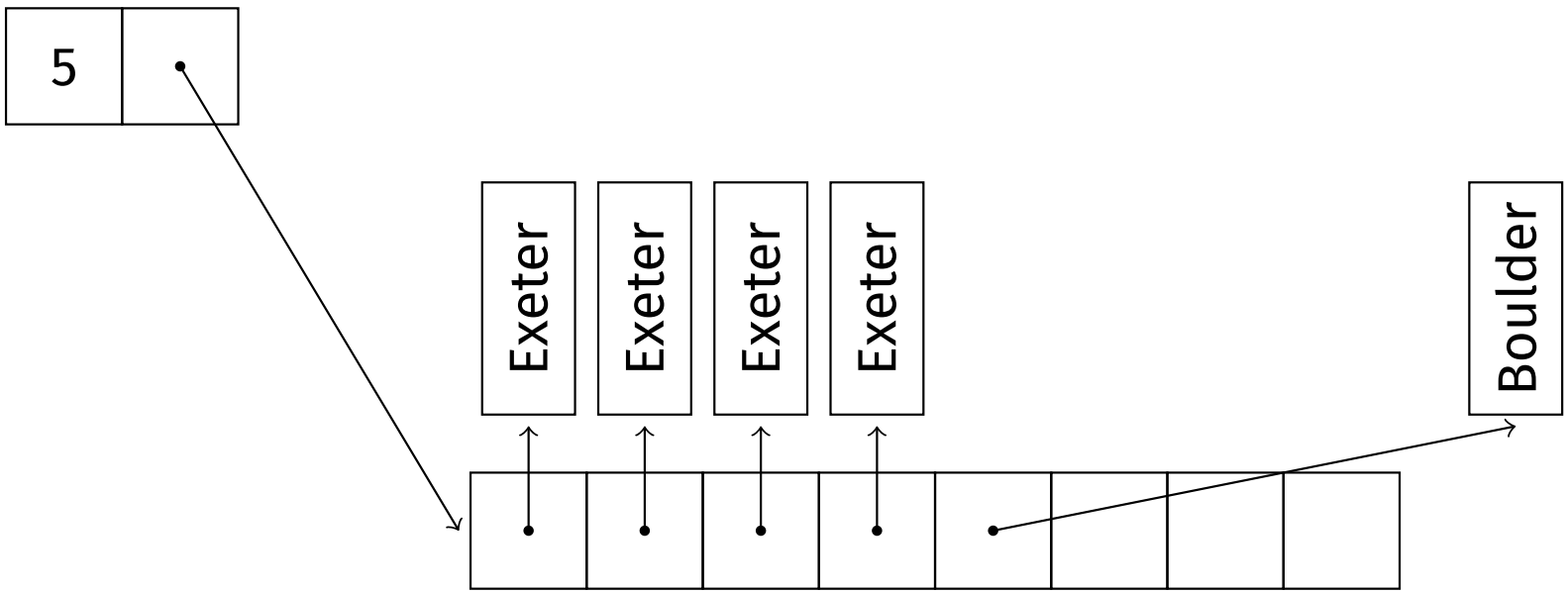

C++11 introduces the concept of rvalue references, making it possible to recognise and profit from move opportunities.

Value categories

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- Expressions in C++ are either lvalues or rvalues.
- Lvalue expressions evaluate to persistent values whose address can be taken, such as
  - names of variables
  - calls to functions returning lvalue references (`T&`, `const T&`)

```
size_t i = 5;
std::vector<int> v(10);
const size_t &ref = i; // i is an lvalue
v.at(ref) = 25;        // v, ref and v.at(ref) too
```

- All other expressions are rvalues. Intuitively, rvalues are typically unnamed temporary objects.

```
int a = 1, b = 2;
int c = (a + b);              // (a + b) is an rvalue,
double x = std::cos(0.0); // 0 and std::cos(0.0) too
```

- In general, value movement is safe only if the source is an rvalue.

Rvalue references

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C++11 introduces the concept of rvalue references. Unlike “normal” references (*lvalue references*), they may be bound only to rvalues.

Example: Move constructors.

```
class C {
 public:
  C(const C &other);      // copy constructor
  C(C &&other) noexcept; // move constructor
};

C makeC();

int main() {
  C c1;
  C c2(c1);              // lvalue: copy
  C c3(makeC());         // rvalue: move
  C c4(std::move(c1)); // rvalue: move
}
```

Move constructors

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It is very uncommon to have to implement a move constructor or assignment operator manually. The compiler automatically generates them for each class that fulfils certain conditions, and the default implementation typically does the right thing.

```
class Person {
 public:
  std::string name_;
  int age_;
};
```

The compiler-generated move constructor looks like this:

```
Person::Person(Person &&other) noexcept
  // Call the move constructors of all member variables
  : name_(std::move(other.name_)),
    age_(std::move(other.age_))
{}
```

Requirements

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Neither a move constructor nor an assignment operator are automatically generated if:

- the class has any user-declared copy constructors, copy assignment operators or destructors
- the class has any data members that can't be moved
- any base class can't be moved.

This restriction applies even if the user-declared special functions are empty or declared as `= default`!

Consequences for JEDI

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A lot of classes in JEDI declare

- an empty destructor and/or
- a copy constructor that prints a tracing message in addition to copying data members

and are thus non-movable.

Examples: `oops::Variables`, `eckit::LocalConfiguration`, `ioda::ObsVector`.

Guidelines

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Rule of zero

Avoid having to implement any of the special member functions.

Rule of five

If you have to declare any of the following special member functions:

- destructor
- copy constructor
- move constructor
- copy assignment operator
- move assignment operator

you should normally declare all of them (possibly as `= default` or `= delete`).