# IMPROVING AUTOMATIC DIFFERENTIATION OF OBJECT-ORIENTED PARADIGMS USING CLAD

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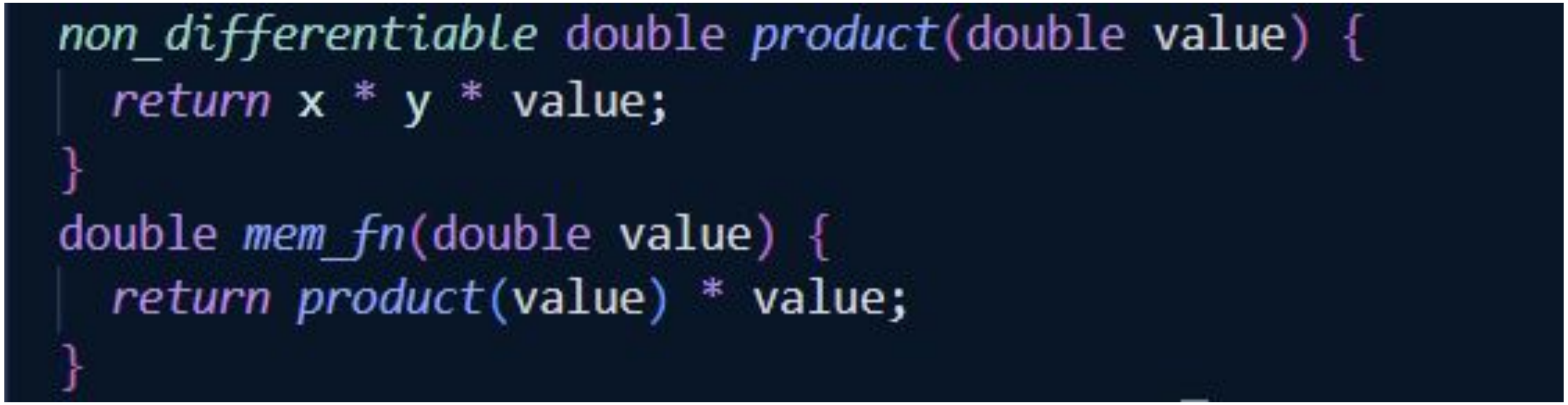
# WHAT WE ACHIEVED

- Enhanced the clad object-oriented differentiable model by incorporating non-differentiable attributes.
- Introduced support for reference return types in clad's reverse mode.
- Upon facilitating the reference return type, we also activated operator overloading in both forward and reverse modes.
- Enabled user-defined derivative functions for operator overloads.

# WHAT WE ACHIEVED

- https://github.com/vgvassilev/clad/pull/568
- https://github.com/vgvassilev/clad/pull/605
- https://github.com/vgvassilev/clad/pull/601(complete, waiting to be merged)
- https://github.com/vgvassilev/clad/pull/619(complete, will be rebased on PR601)

- NON-DIFFERENTIABLE ATTRIBUTES.

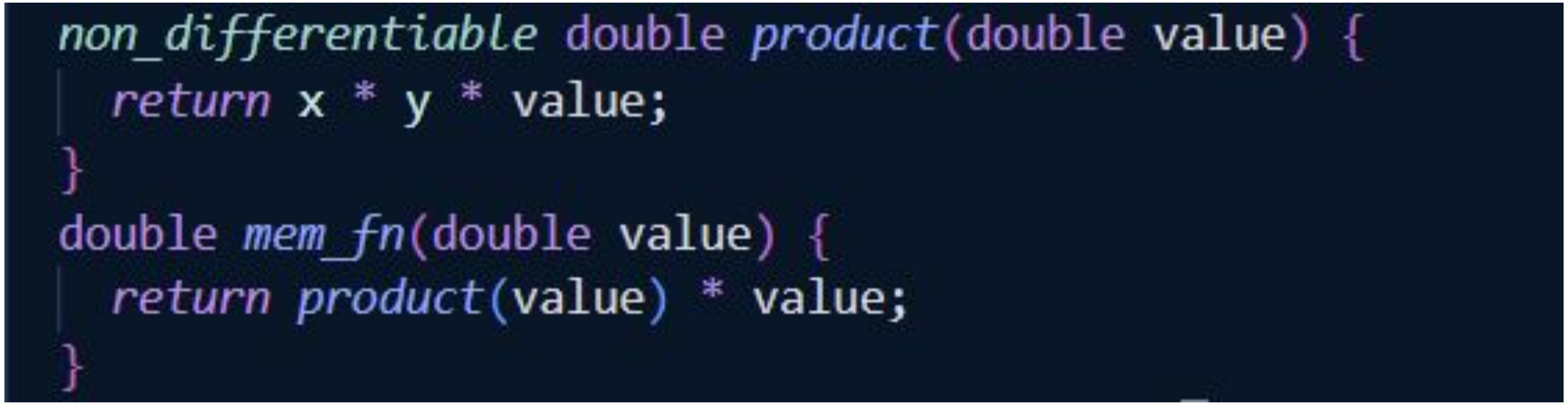


```
non_differentiable double product(double value) {
  return x * y * value;
}
double mem_fn(double value) {
  return product(value) * value;
}
```

- non_differentiable is an attribute that marks specific fields or methods in a class, indicating they should not be differentiated.

- Here, the product method in the SimpleFunctions class has been tagged with this attribute, signifying that any differentiation tools or routines should bypass or ignore this method.

- NON-DIFFERENTIABLE ATTRIBUTES.



```
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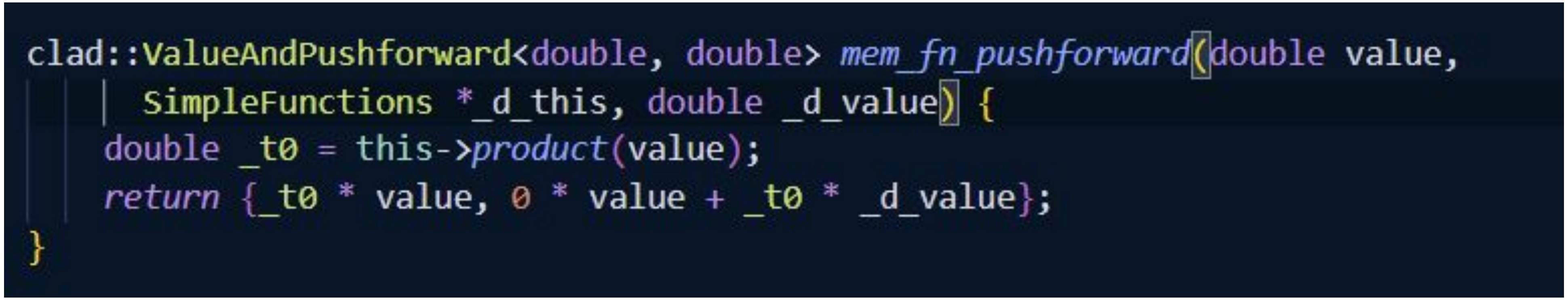
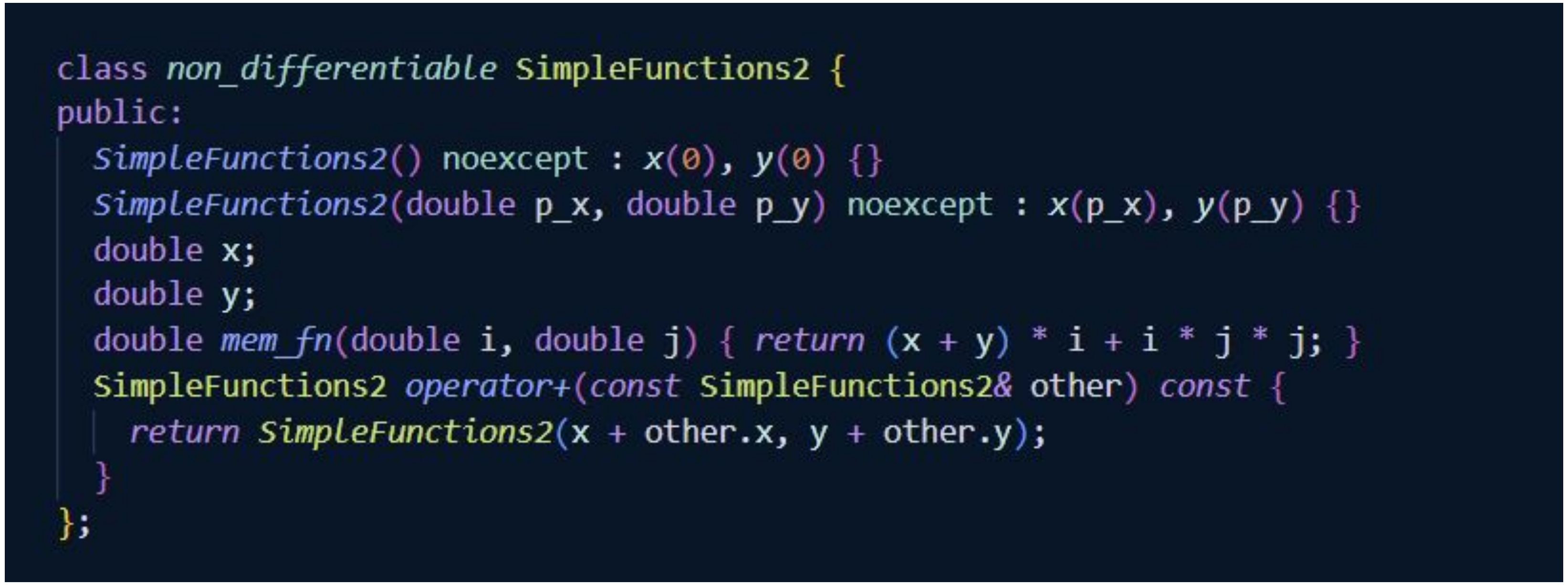


```
clad::ValueAndPushforward<double, double> mem_fn_pushforward(double value,
      SimpleFunctions *_d_this, double _d_value) {
    double _t0 = this->product(value);
    return {_t0 * value, 0 * value + _t0 * _d_value};
}
```

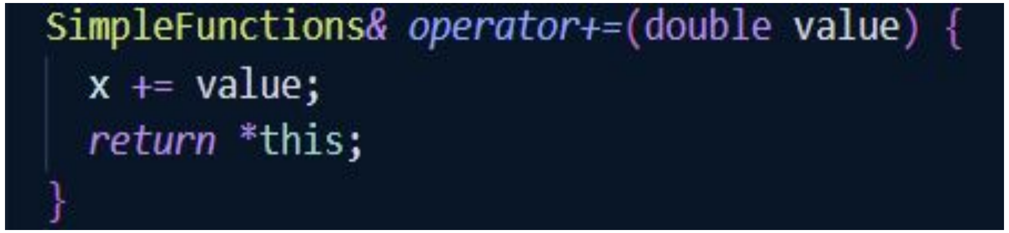
- NON-DIFFERENTIABLE ATTRIBUTES.



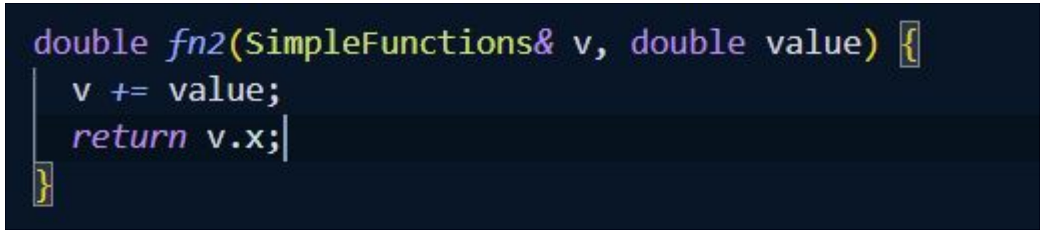
```cpp
class non_differentiable SimpleFunctions2 {
public:
  SimpleFunctions2() noexcept : x(0), y(0) {}
  SimpleFunctions2(double p_x, double p_y) noexcept : x(p_x), y(p_y) {}
  double x;
  double y;
  double mem_fn(double i, double j) { return (x + y) * i + i * j * j; }
  SimpleFunctions2 operator+(const SimpleFunctions2& other) const {
    return SimpleFunctions2(x + other.x, y + other.y);
  }
};
```

- When applied to a class, it suggests that differentiation tools should bypass or ignore all of its fields and member functions.

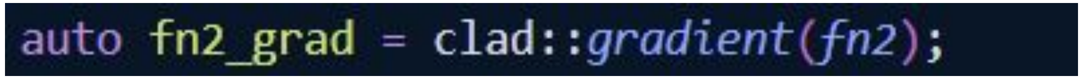
- OPERATOR OVERLOADS



```
SimpleFunctions& operator+=(double value) {
  x += value;
  return *this;
}
```



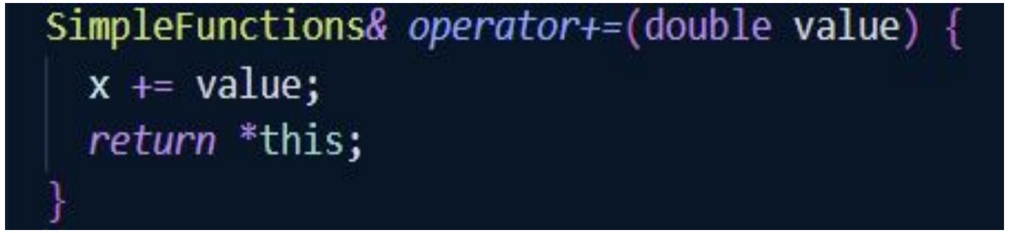
```
double fn2(SimpleFunctions& v, double value) {
  v += value;
  return v.x;
}
```



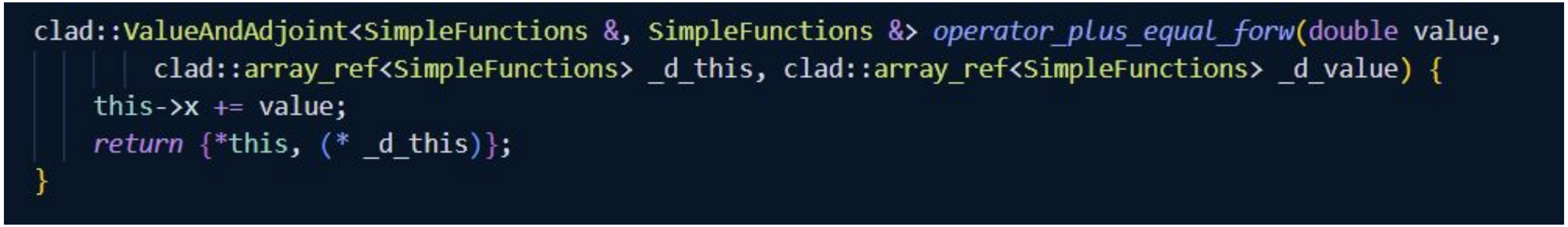
```
auto fn2_grad = clad::gradient(fn2);
```

- The above example demonstrates the differentiation of operator overloads using clad.
- A crucial enhancement added is the support for operators with reference return types, such as the operator+= in the SimpleFunctions class.

- REFERENCE RETURN TYPE



```
SimpleFunctions& operator+=(double value) {
  x += value;
  return *this;
}
```

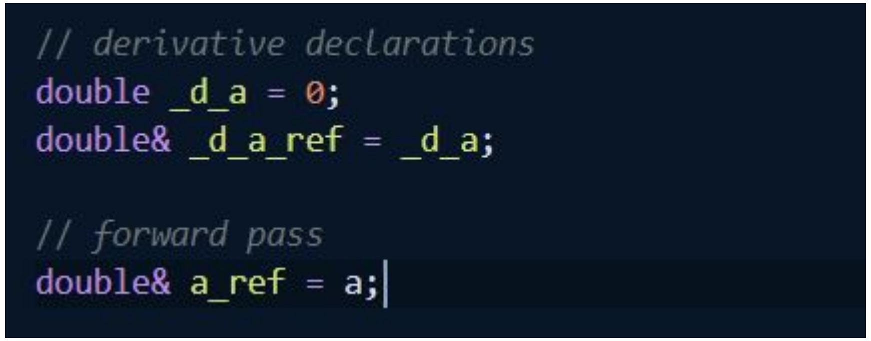


```
clad::ValueAndAdjoint<SimpleFunctions &, SimpleFunctions &> operator_plus_equal_forw(double value,
        clad::array_ref<SimpleFunctions> _d_this, clad::array_ref<SimpleFunctions> _d_value) {
    this->x += value;
    return {*this, (* _d_this)};
}
```

- A crucial enhancement added is the support for operators with reference return types, such as the operator+= in the SimpleFunctions class.

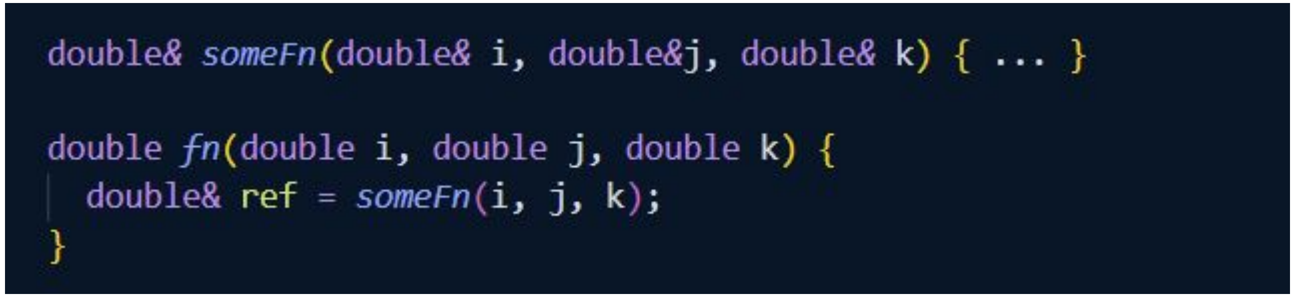
- We introduce a “_forw” function for reference return type.

- REFERENCE RETURN TYPE



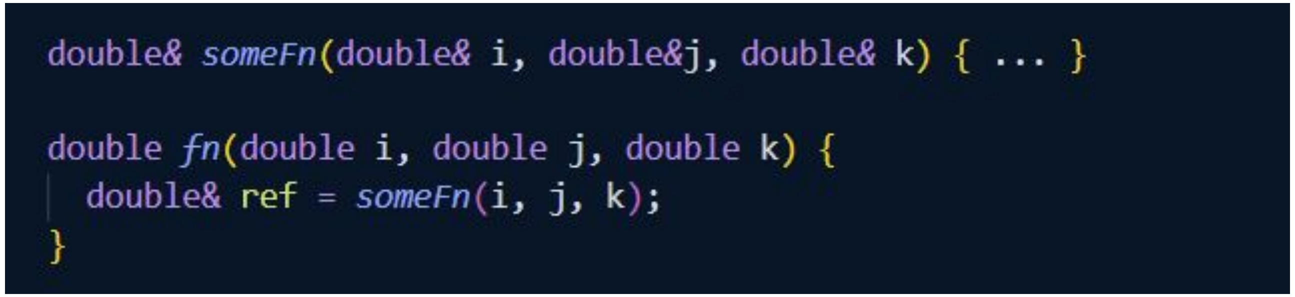
```
// derivative declarations
double _d_a = 0;
double& _d_a_ref = _d_a;

// forward pass
double& a_ref = a;
```

- In the above example, we can easily point _d_a_ref to _d_a because the derivative of a is known at compile time. This is not always the case, for example, consider the following code.



```
double& someFn(double& i, double&j, double& k) { ... }

double fn(double i, double j, double k) {
  double& ref = someFn(i, j, k);
}
```

- REFERENCE RETURN TYPE

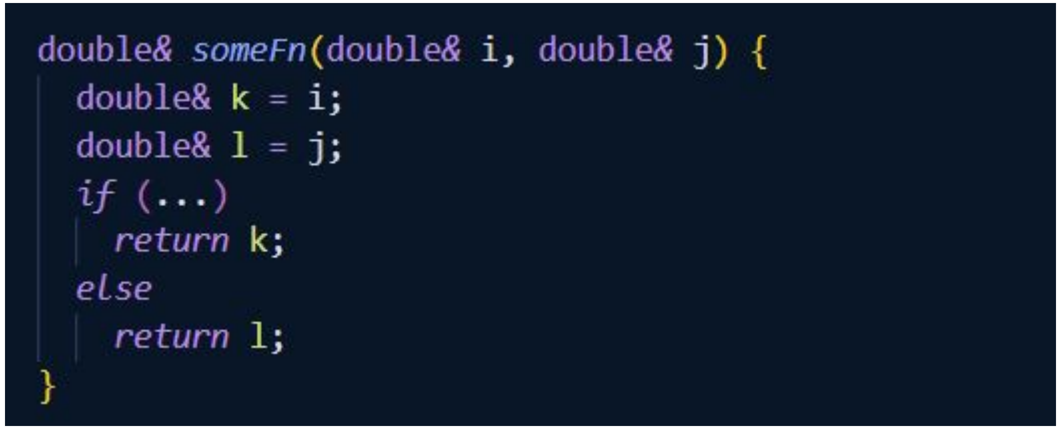


```
double& someFn(double& i, double&j, double& k) { ... }

double fn(double i, double j, double k) {
  double& ref = someFn(i, j, k);
}
```

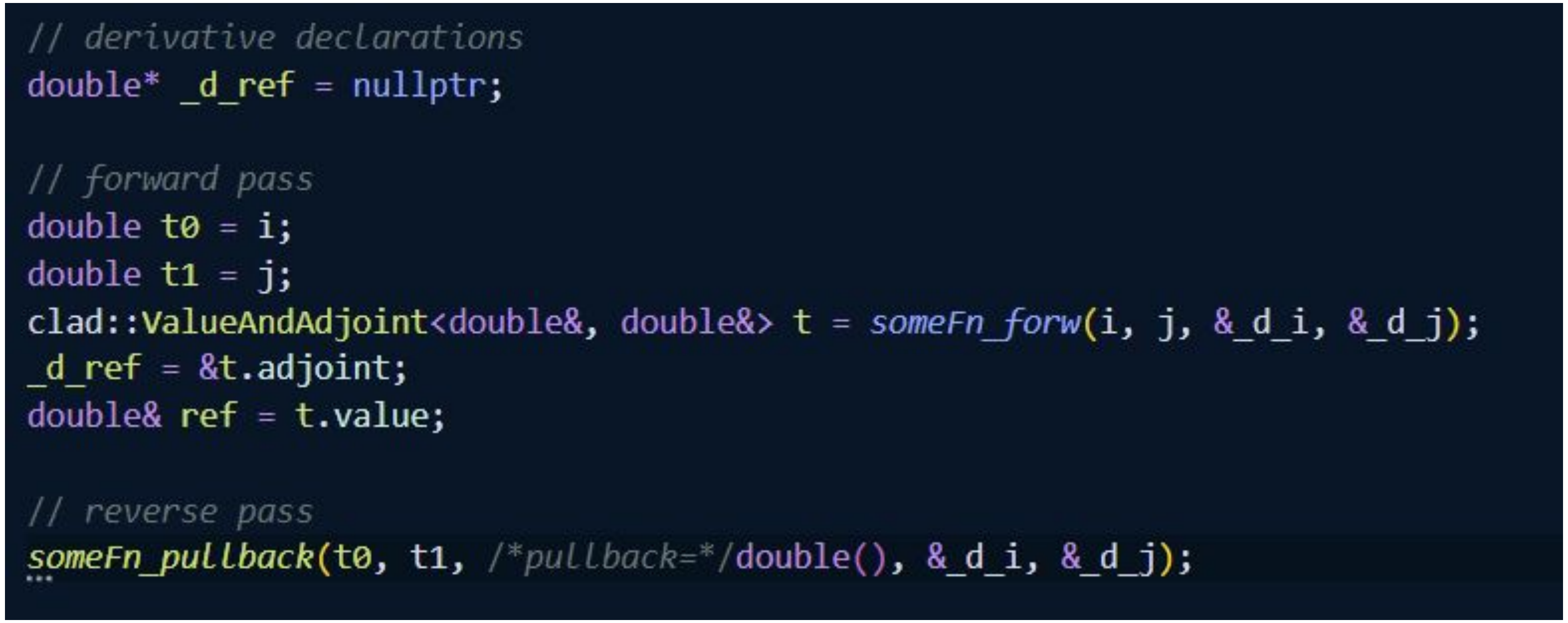
- We cannot determine which variable ref is referencing at compile time. Thus, we also cannot determine which derivative should _d_ref refer to.

- That’s why we need “_forw” function.

- REFERENCE RETURN TYPE

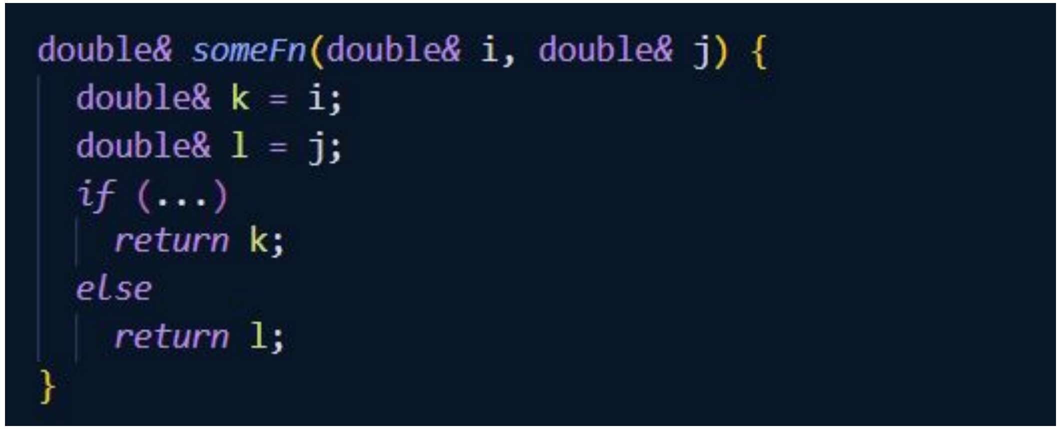


```
double& someFn(double& i, double& j) {
  double& k = i;
  double& l = j;
  if (...)
    return k;
  else
    return l;
}
```



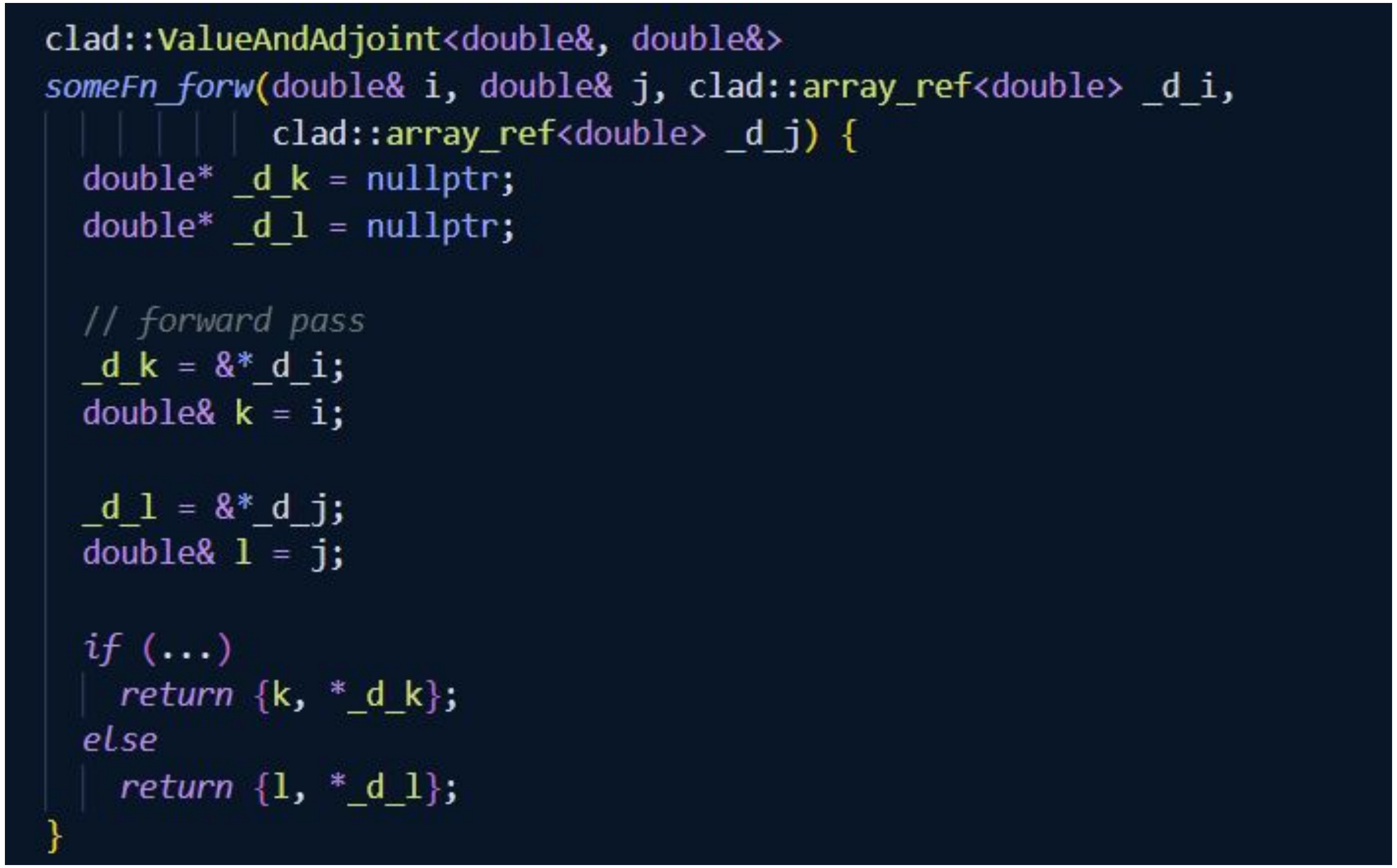
```
// derivative declarations
double* _d_ref = nullptr;

// forward pass
double t0 = i;
double t1 = j;
clad::ValueAndAdjoint<double&, double&> t = someFn_forw(i, j, &_d_i, &_d_j);
_d_ref = &t.adjoint;
double& ref = t.value;

// reverse pass
someFn_pullback(t0, t1, /*pullback=*/double(), &_d_i, &_d_j);
```

- REFERENCE RETURN TYPE



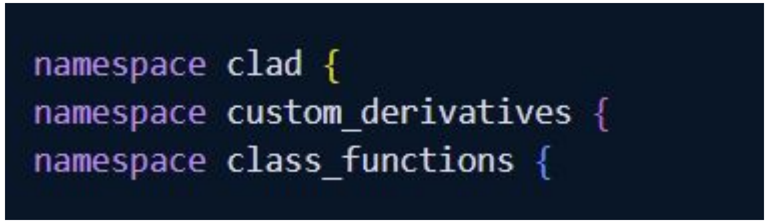
```
double& someFn(double& i, double& j) {
  double& k = i;
  double& l = j;
  if (...)
    return k;
  else
    return l;
}
```

- The corresponding someFn_forw will be:

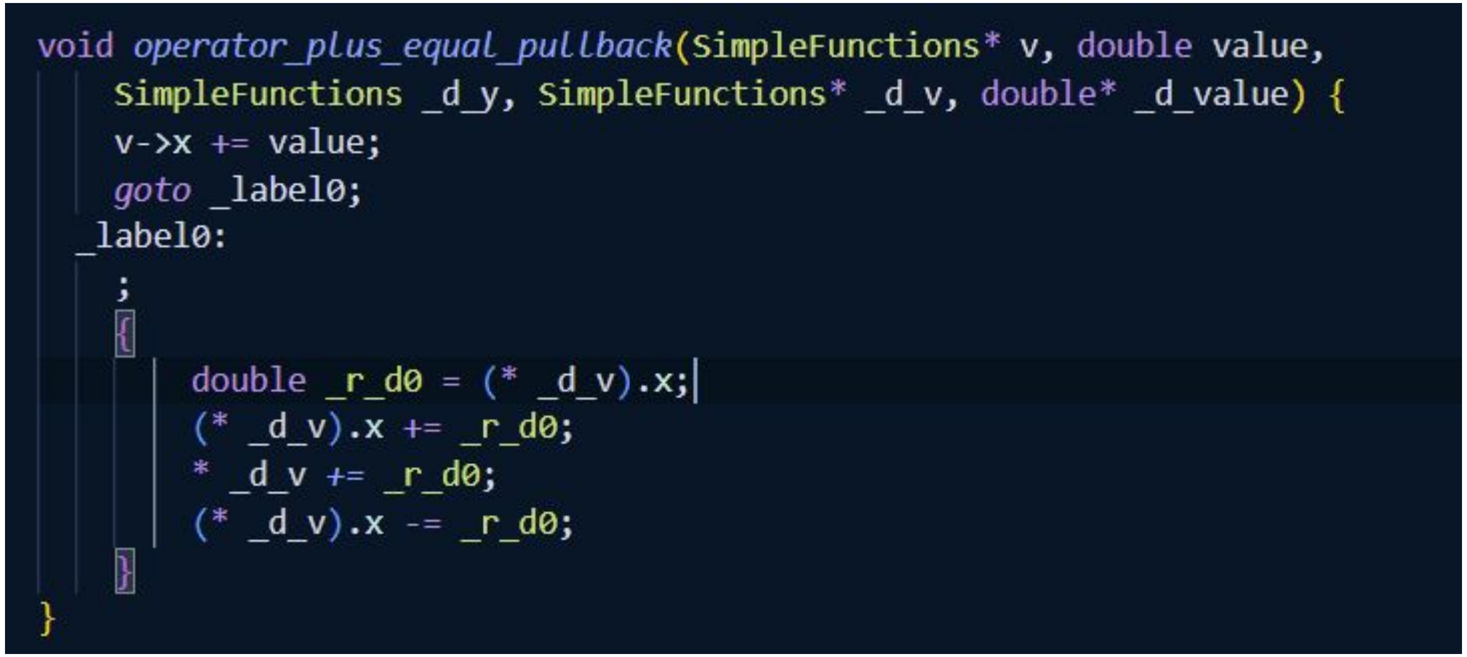


```
clad::ValueAndAdjoint<double&, double&>
someFn_forw(double& i, double& j, clad::array_ref<double> _d_i,
            clad::array_ref<double> _d_j) {
  double* _d_k = nullptr;
  double* _d_l = nullptr;

  // forward pass
  _d_k = &*_d_i;
  double& k = i;

  _d_l = &*_d_j;
  double& l = j;

  if (...)
    return {k, *_d_k};
  else
    return {l, *_d_l};
}
```

- CUSTOM DERIVATIVES FOR SPECIAL MEMBER FUNCTIONS



```
namespace clad {
namespace custom_derivatives {
namespace class_functions {
```



```
void operator_plus_equal_pullback(SimpleFunctions* v, double value,
    SimpleFunctions _d_y, SimpleFunctions* _d_v, double* _d_value) {
    v->x += value;
    goto _label0;
  _label0:
    ;
    {
        double _r_d0 = (* _d_v).x;
        (* _d_v).x += _r_d0;
        * _d_v += _r_d0;
        (* _d_v).x -= _r_d0;
    }
}
```

- The code showcases user-defined derivatives for operator overloads, allowing for custom differentiation behavior.

- By employing the clad::custom_derivatives namespace, users can specify custom derivatives for operators like operator+=, tailoring differentiation to specific class implementations.

# MISSING SUPPORT FOR CPP FEATURE

- Suppoer try-catch blocks to enable some std namespace functions differentiation.
- Support switch statements in the reverse mode.
- Support special member functions like constructors in both the forward and the reverse mode.
- Support custom derivatives for special member functions.

# THANK YOU!