

[M]^s

挑战与未来



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Building a better connected world



www.mindspore.cn

关于本课程

1. 课程背景

- AI框架中自动微分的重要性

2. 课程内容

- 微分基本概念：数值微分 - 符号微分 - 自动微分
- 自动微分模式：前向微分 – 后向微分 – 雅克比原理
- 具体实现方式：表达式或图 – 操作符重载OO – 源码转换 AST
- MindSpore实现：基于图表示的源码转换Graph Base AST
- 自动微分的挑战与未来

AD Challenge - Ease of use

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- 理想中的自动微分是对**数学表达**的分
解、微分和组合过程
- 实际中的自动微分是对**程序表达**的分
解、微分和组合过程

$$\begin{aligned}l_1 &= x \\l_{n+1} &= 4l_n(1 - l_1) \\f(x) &= l_4 = 64x(1 - x)(1 - 2x)^2(1 - 8x + 8x^2)^2\end{aligned}$$



```
f(x):  
    v = x  
    for i = 1 to 3:  
        v = 4 * v * (1 - v)  
    return v
```

AD Challenge - Ease of use (I)

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控制流表达问题

```
 $l_1 = x$ 
 $l_{n+1} = 4l_n(1 - l_1)$ 
 $f(x) = l_4 = 64x(1 - x)(1 - 2x)^2(1 - 8x + 8x^2)^2$ 
```



```
f(x):
    v = x
    for i = 1 to 3:
        v = 4 * v * (1 - v)
    return v
```

识别程序表达中用于计算控制流的运算部分，并将其排除在微分过程外

复杂数据类型

```
 $dx = x$ 
 $l_{n+1} = 4l_n(1 - l_1)$ 
 $f(x) = l_4 = 64x(1 - x)(1 - 2x)^2(1 - 8x + 8x^2)^2$ 
```



```
<aexp> ::= NUMBER | STRING | VAR | BOOLEAN | PRIMOP
Python ::= [List, Enum, Tuple, Dict, DefaultDict]
C++ ::= [size_t, whcar_t, enum, struct , STL::list]
```

AD Challenge - Ease of use (II)

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语言特性

- 多态、异常处理、调试、IO处理、继承等

需求重写

- 物理模拟、游戏引擎、气候模拟有DSL属性

AD Challenge - Performance

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程序与微分表达

$$f = x^3$$

$$dx = 3 * x^2$$

```
def fun(x):
    t = x * x * x
    return t
```

```
def dfun(x):
    dx = 3 * x * x
    return dx
```

```
def fun(x):
    t = x * x
    v = x * t
    dx = 3 * t
    return v, dx
```

AD Challenge - Performance

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额外中间变量

$$\bar{v}_i = \frac{\partial y_i}{\partial v_i}$$

Forward Primal Trace

$$\begin{array}{ll} v_{-1} = x_1 & = 2 \\ v_0 = x_2 & = 5 \end{array}$$

$$v_1 = \ln v_{-1} = \ln 2$$

$$v_2 = v_{-1} \times v_0 = 2 \times 5$$

$$v_3 = \sin v_0 = \sin 5$$

$$v_4 = v_1 + v_2 = 0.693 + 10$$

$$v_5 = v_4 - v_3 = 10.693 + 0.959$$

$$y = v_5 = 11.652$$

Reverse Adjoint (Derivative) Trace

$$\begin{array}{lll} \bar{x}_1 = \bar{v}_{-1} & & = 5.5 \\ \bar{x}_2 = \bar{v}_0 & & = 1.716 \end{array}$$

$$\bar{v}_{-1} = \bar{v}_{-1} + \bar{v}_1 \frac{\partial v_1}{\partial v_{-1}} = \bar{v}_{-1} + \bar{v}_1 / v_{-1} = 5.5$$

$$\bar{v}_0 = \bar{v}_0 + \bar{v}_2 \frac{\partial v_2}{\partial v_0} = \bar{v}_0 + \bar{v}_2 \times v_{-1} = 1.716$$

$$\bar{v}_{-1} = \bar{v}_2 \frac{\partial v_2}{\partial v_{-1}} = \bar{v}_2 \times v_0 = 5$$

$$\bar{v}_0 = \bar{v}_3 \frac{\partial v_3}{\partial v_0} = \bar{v}_3 \times \cos v_0 = -0.284$$

$$\bar{v}_2 = \bar{v}_4 \frac{\partial v_4}{\partial v_2} = \bar{v}_4 \times 1 = 1$$

$$\bar{v}_1 = \bar{v}_4 \frac{\partial v_4}{\partial v_1} = \bar{v}_4 \times 1 = 1$$

$$\bar{v}_3 = \bar{v}_5 \frac{\partial v_5}{\partial v_3} = \bar{v}_5 \times (-1) = -1$$

$$\bar{v}_4 = \bar{v}_5 \frac{\partial v_5}{\partial v_4} = \bar{v}_5 \times 1 = 1$$

$$\bar{v}_5 = \bar{y} = 1$$

额外中间变量

二阶微分方程的一般形式：

$$F(x, y, y', y'') = 0$$

其中， x 是自变量， y 是未知函数， y' 是 y 的一阶导数， y'' 是 y 的二阶导数。

$$\frac{d^2y}{dx^2} = \frac{d}{dy} \left(\frac{dy}{dx} \left(\frac{dx}{x} \right) \right)$$

AD Challenge - Performance

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重计算与编译优化

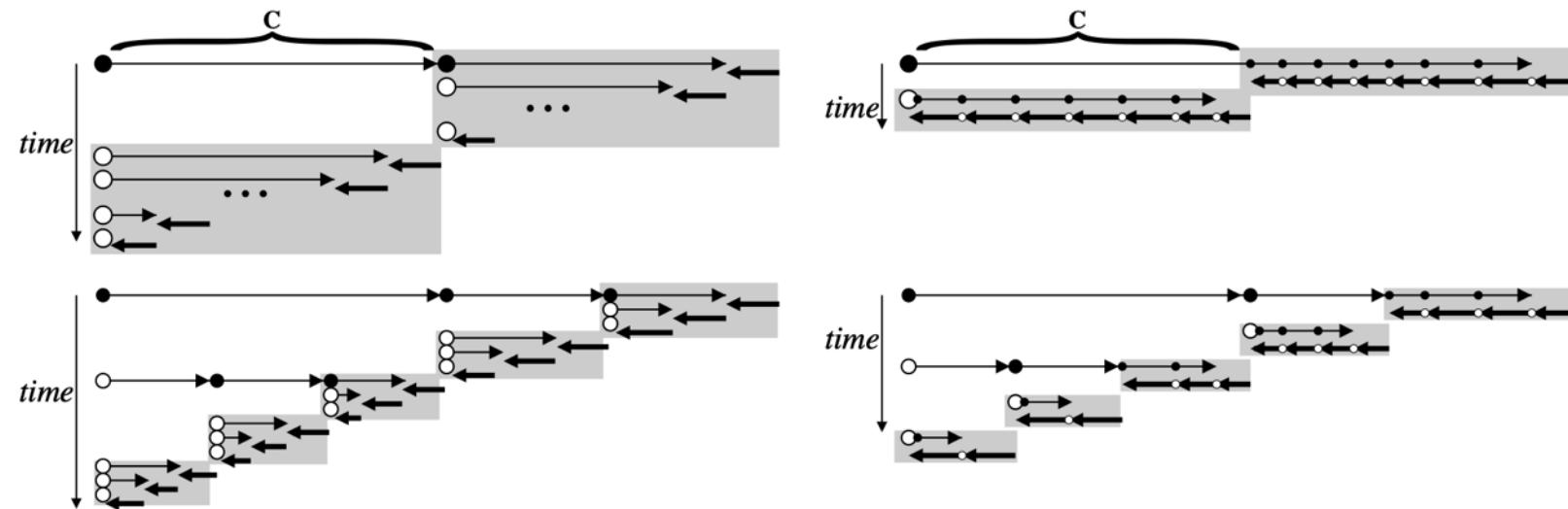


Figure 3: Checkpointing with the Recompute-All (*left*) and Store-All (*right*) approaches. The shaded areas reproduce the basic pattern of the chosen approach. *top*: single checkpointing, *bottom* nested checkpointing.

可微编程

将自动微分技术与语言设计、编译器 / 解释器甚至 IDE 等工具链等深度融合，将微分作为语言中 first-class feature

Conclusion

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1. 自动微分挑战主要集中在易用性和性能两方面
2. 易用性受限于控制流、数据类型等语言特性以外，还受限于领域需求
3. 性能主要以程序表达与微分表达结合，编译，甚至高阶微分等引起

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TEAMS

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