A Novel Data Layout Optimization in BiSheng Compiler

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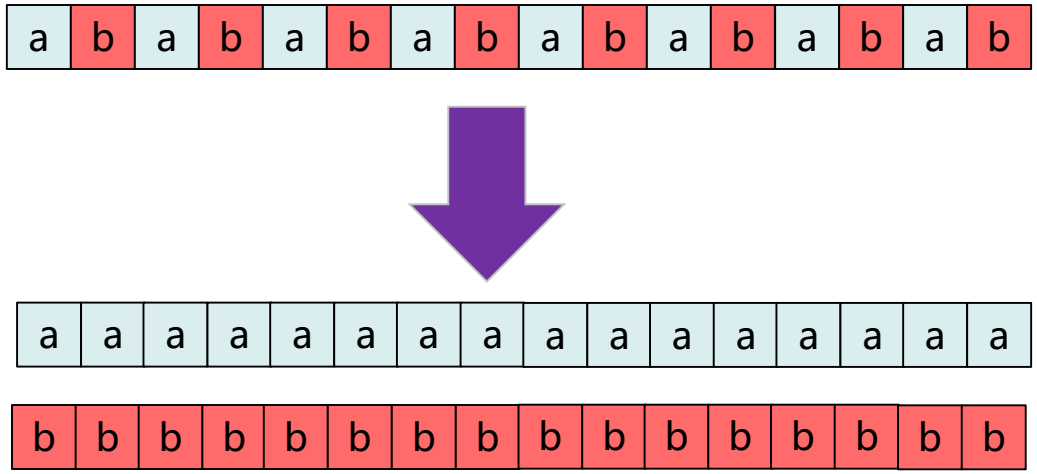
BiSheng Compiler

- **LLVM-based C/C++/Fortran compiler developed by Huawei.**
  - Under development since late 2019.
- **Primarily optimized for Kunpeng AArch64 servers.**
- **Supports X86 as well.**
- **We have talked about BiSheng internals in LLVM Dev meeting and other conferences in the past couple of years.**

Data layout optimizations

- **Many well-known data layout optimizations in the literature.**
  - Array of Structure to Structure of Arrays. (AKA structure peeling).
    - See the picture.
  - Array reorganization.
  - Structure repacking.



- **Improve spatial locality of memory accesses**
  - Better cache utilization.
  - Better memory bandwidth utilization.

- **Critical for SPEC CPU benchmarks.**

- **Previous talk at LATHC workshop (CGO 2023) covers our new approach to structure peeling**

The new data layout optimization

- **We introduce our new optimization: Nested Container Flattening**
- **Will explain the name during this presentation.**

- **What is covered:**
  - High level description of the transformation and the motivation behind it.
  - Major issues in legality analysis

- **What is not covered**
  - Details of transformation
  - Details of legality analysis
  - Cost analysis

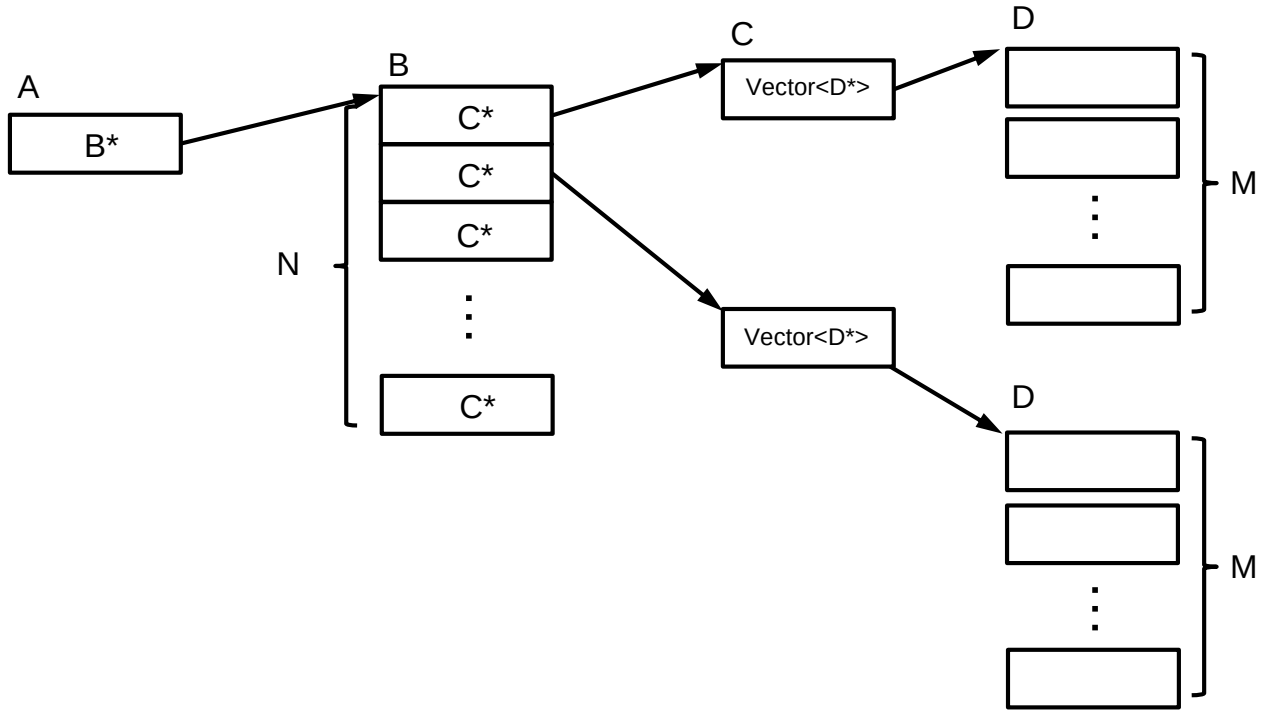
The problem

```
class A {

public:
   B *b;

};
```

```
class B {

public:
   C *c;

};
```

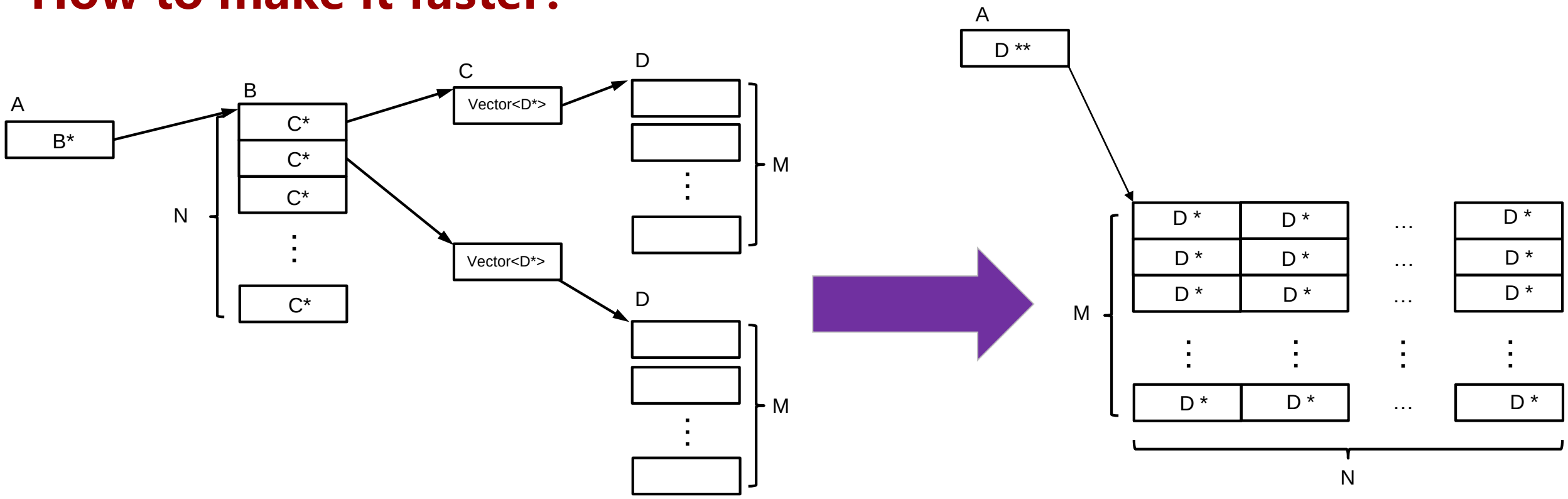
```
class C {

public:
   std::vector<D *> d;

};
```

```
void func(A *a) {
  ……
  a->b[i].c->d[k]->DoWork();
  ……
}
```



- Objects in different arrays are likely to be in different memory locations.
- Each load is likely to cause a cache miss.
- Intermediate loads has no other use.

How to make it faster?



- All D pointers reachable from an A object are now copied within that object.
- Old D pointers may or may not be removed.
- Nested Container Flattening

Legality analysis

- **Compiler needs very deep understanding of life time of the objects involved.**
- **This requires the ability to analyze where the objects are created and where the fields are written to or read from.**
- **It looks like we need pointer analysis.**
- **In a C++ workload, it is not likely that pointer analysis can reach the precision level that we need, while being fast enough.**
- **We mostly rely on preserving C++ source code level information and analyzing that in the mid-end.**
  - › Full legality analysis is complex and has many details.
  - › We just explain two central concepts: Nested objects, Containers.
  - › This completes explanation of the name: Nested Container Flattening.

Legality analysis: Nested Objects

- **Saying b is *Nested* in class A means**
  - There is no access to b outside of class A member functions.
  - Entire lifetime of b, from allocation to deallocation, is within the lifetime of an A object.
  - Relying on C++ source code information to prove this property requires considering many different C++ features and intricacies. Some pointer analysis is still needed.
  - It is easier to reason about a nested B object.
    - e.g. Consider only relevant B member functions.
    - See the toy example on the right.
    - Only two functions are relevant.

```
class B {
  int x;
  int y;

public:
  void func1();
  void func2();
  void func3();
  void func4();
};
```

```
class A {

  B *b;

public:
  void func() {
    b = new B();
    b->func1();
    b->func2();
    delete b;
  }
};
```

Legality Analysis: Containers

- What does it mean to say object b is a container?
- Intuitively, that means some information is passed to b and preserved.

```
class A {

   B *b; // b is nested in A.
   // only b->addNewObject() is called.


};
```

```
class B {
  int x;
  C* c; // array of C objects

public:
  void addNewObject(C &c);
  void removeLast();
  void updateLast();
  void updateAll();
};
```

How useful is an optimization like this?

- **Data layout optimizations are usually too complex.**
  - It is hard to prove their legality
  - It is hard to perform the transformation
- **The optimization is not triggered that often.**
- **We get 35% improvement on a SPEC benchmark, what else?**
- **The infrastructure developed is usually useful beyond the optimization itself.**
- **Many DL opts require a good pointer analysis.**
  - Pointer analysis is useful beyond these optimizations.
- **We believe our ideas for legality analysis of this new transformation are useful beyond this optimization.**
  - Some potential applications of these techniques for other optimizations are under investigation.

Thank you

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