Realization of Random Forest for Real-Time Evaluation through Tree Framing

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Project setting

Goal Hardware-awareness of Machine Learning
Why does this matter?

- Reduce energy costs by reducing hardware requirements
- Reduce training/prediction time by better hardware utilization

Focus here How can we concurrently apply a given model on a small device in real-time?

Abstract

Fact Random Forests are still one of the best blackbox learners available

Question How to optimize RF execution?

Basic idea Utilize the structure of trained tree

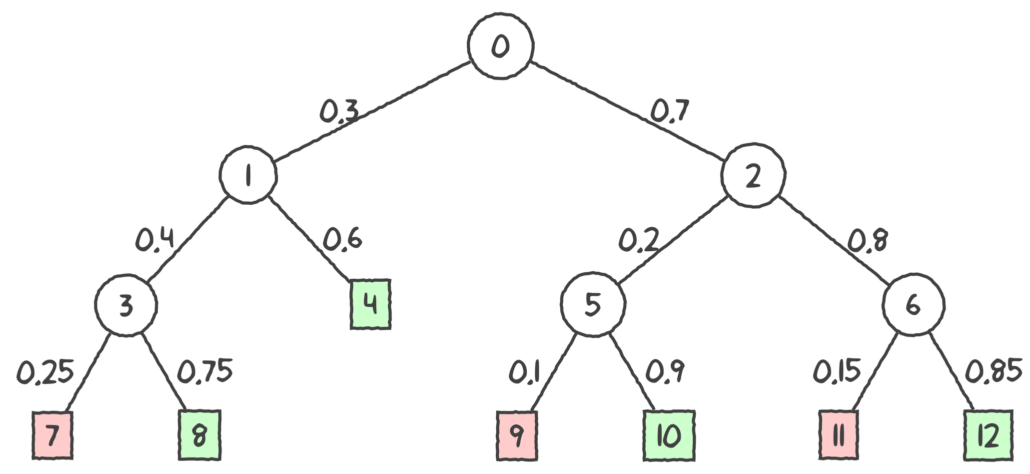
→ **Branch-probability** $p_{i \to j}$

→ **Path-probability** $p(\pi) = p_{\pi_0 \to \pi_1} \cdot \ldots \cdot p_{\pi_{L-1} \to \pi_L}$

→ **Expected path length** $\mathbb{E}[L] = \sum_\pi p(\pi) \cdot |\pi|$

Idea Use $E[L]$ to optimize memory-layout of trees

Example



$$p((0,1,3)) = 0.3 \cdot 0.4 \cdot 0.25 = 0.03$$
$$p((0,2,6)) = 0.7 \cdot 0.8 \cdot 0.85 = 0.476$$

Implementation 1: Native Tree

```
Node t[] = {/* ... */};
bool predict(short const * x){
    unsigned int i = 0;
    while(!t[i].isLeaf) {
        if (x[t[i].f] <= t[i].s) {
            i = t[i].l;
        } else {
            i = t[i].r;
        }
    }
    return t[i].pred;
}
```

Idea Iterate array of tree-nodes

+ Simple to implement
+ Small 'Hot'-Code
- Requires D-Cache (array)
- Requires I-Cache (code)
- Requires indirect mem. access

Implementation 2: If-Else Tree

```
bool predict(short const * x){
    if(x[0] <= 8191){
        if(x[1] <= 2048){
            return true;
        } else {
            return false;
        }
    } else {
        if(x[2] <= 512){
            return true;
        } else {
            return false;
        }
    }
}
```

Idea Unroll tree into `if-else`

+ No indirect mem. access
+ Compiler optimizes aggresivly
+ Only I-Cache required
- Code does not fit I-Cache
- No 'hot'-code

Optimization for Native Tree

Compulsory cache misses
→ Cache memory is not enough to hold complete array
→ Leaf-nodes only store the prediction. Pointer to children not necessary
Solution Store prediction directly in 'parent' node

Capacity and conflict cache misses
→ Pre-fetching does not work, if nodes are discontinuously arranged
→ Layout nodes in array so that they respect access pattern
Solution Greedily put nodes with highest probability in same cache set

- Put the root node into current working set $\mathcal{C}$. Set $i = 0$
- If $|\mathcal{C}| \leq \tau$: $\mathcal{C} = \mathcal{C} \cup \arg\max(p(i \to l(i)), p(i \to r(i)))$
- Continue until $|\mathcal{C}| \geq \tau$
- Place nodes in $\mathcal{C}$ continously in array

Optimization for If-Else Tree

Compulsory cache misses
→ Cache memory is not enough to store all code
→ Increase chance, that nodes with higher probabilities are in the cache
Solution Swap nodes if $p(i \to l(i)) \geq p(i \to r(i))$

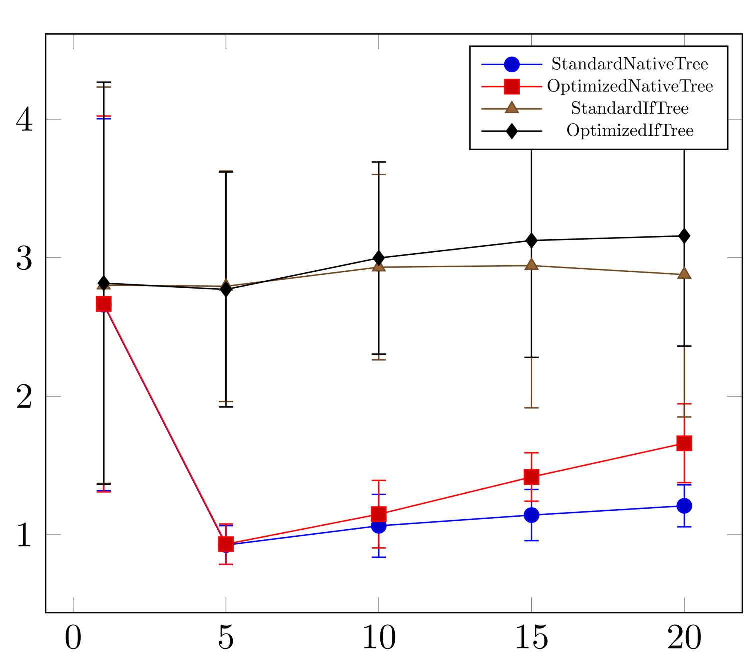
Capacity and conflict cache misses
→ Cache memory is not enough to store all code
→ Computation kernel of tree might fit into cache
Solution Compute computation kernel for budget β

$$\mathcal{K} = \arg\max \left\{ p(\mathcal{T}) \middle| \mathcal{T} \subseteq \mathcal{T} \text{s.t.} \sum_{i \in \mathcal{T}} s(i) \leq \beta \right\}$$

- Start with the root node
- Greedily add nodes until budget exceeded

Note Estimate $s(\cdot)$ based on assembly analysis

Results on X86 CPUs



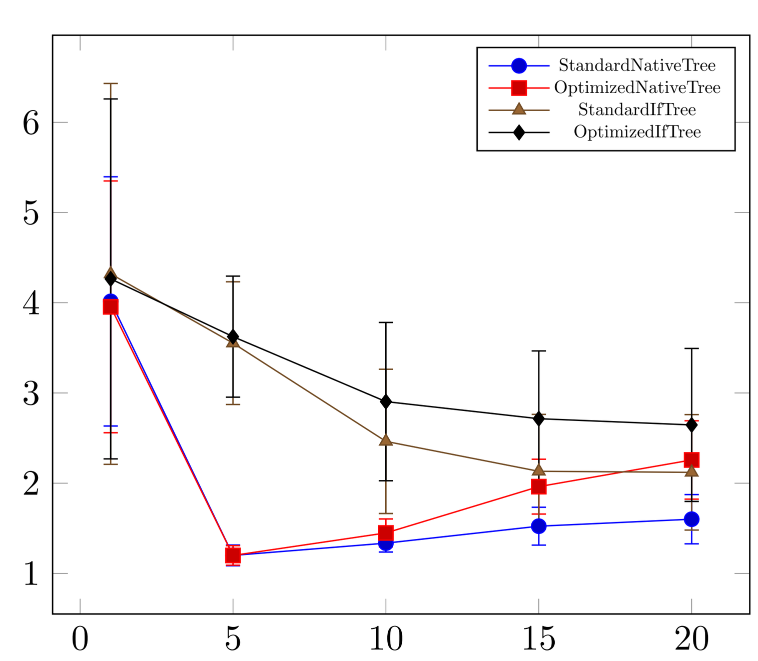
Results

- Optimizations improve performance
- `if-else` trees are clear winner

Interpretation

- Large I-Cache (256 KiB) favors `if-else`
- Compiler can utilize CISC architecture for `if-else`
- `Native` trees do not benefit from I-Cache and CISC

Results on ARM CPUs



Results

- Optimizations improve performance
- No clear winner for larger trees

Interpretation

- Smaller I-Cache (32 KiB) only fits small trees
- Smaller D-Cache (512 KiB) only fits small trees
- Requires more instructions than CISC

Conclusion

Take-away There are multiple ways of implementing Decision Trees on modern hardware

Thus Use code generator to automatically generate *all* possible implementations for a given architecture

We emperical evaluated our generator with a total of 1.800 experiments on 3 architectures

Results Speed-up around ≥ 3 on all architectures (`X86`, `ARM`, `PPC`)

Future Research and Improvements

- Improve compilation time → Generate intermediate language code
- Reduce memory footprint → Re-use common tree parts (subtree matching)
- Mix different implementation types → Switch from if-else to native when branching to deep

References

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Find us on bitbucket
`https://bitbucket.org/sbuschjaeger/arch-forest/`