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

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Motivation

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Goal Have a small, cheap telescope which can be deployed everywhere on earth

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- Pre-train forest on simulated data, then apply it in the real world
- Physicist know Random Forests
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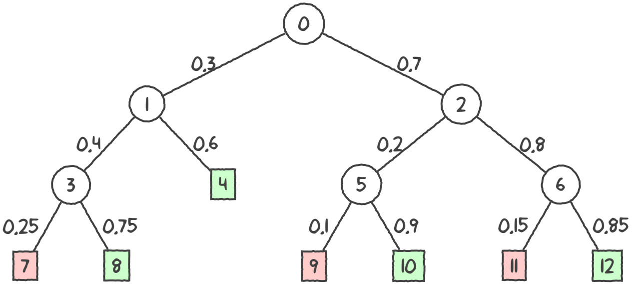
Goal Execute Random Forest in real-time and keep-up with 180 MB/s of data

Constraint Size and energy available is limited → Model must run on embedded system

Recap Decision Trees and Random Forest



- DTs split the data in regions until each region is “pure”
- Splits are binary decisions if x belongs to certain region
- Leaf nodes contain actual prediction for a given region
- RFs built multiple DTs on subsets of the data/features

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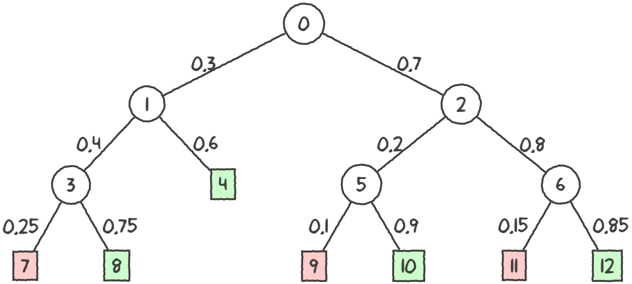

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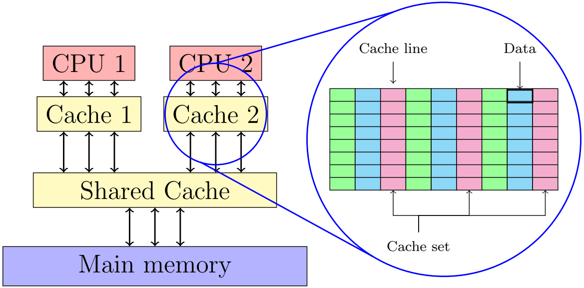
Question How to implement a Decision Tree / Random Forest?

Recap Computer architecture



- CPU computations are much faster than memory access
- Memory-Hierarchy (Caches) is used to hide slow memory
- Caches assume spatial-temporal locality of accesses

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Implementing Decision Trees (1)

Fact There are at-least two ways to implement DTs in modern programming languages

Native-Tree Store nodes in array and iterate it in a loop

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```
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;
}
```

+ Simple to implement
+ Small 'hot'-code
- Requires D-Cache (array)
- Requires I-Cache (code)
- Requires indirect memory access

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If-Else-Tree Unroll tree into `if-else` instructions

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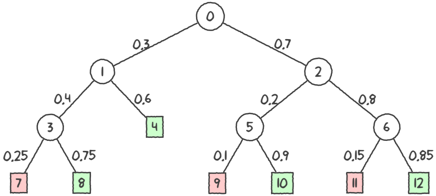
```
bool predict(short const * x){
    if(x[0] <= 8191){
        if(x[1] <= 2048){
            return true;
        } else {
            return false;
        }
    } else {
        if(x[2] <= 512){
            return true;
        } else {
            return false;
        }
    }
}
```

+ No indirect memory access
+ Compiler can optimize aggressively
+ Only I-Cache required
- I-Cache usually small
- No ‘hot’-code

Probabilistic execution model of DTs

Basic idea Analyse the structure of trained tree and keep most important paths in Cache



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 $\mathbb{E}[L] = \sum_\pi p(\pi) \cdot |\pi|$

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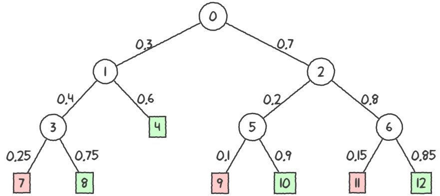

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Example

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

Probabilistic optimizations for DTs

Capacity misses Cache memory is not enough to store all code

But Computation kernel of tree might fit into cache

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Solution Compute computation kernel for budget β

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

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

Note

- Estimate $s(\cdot)$ based on assembly analysis
- Choose β based on the properties of specific CPU model

Probabilistic optimizations for DTs (2)

Further optimizations

- Reduce memory consumption of nodes for `native` trees with clever implementation
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In total Compare 1 baseline method and 4 different implementations

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Questions

- What is the performance-gain of these optimizations?
- How do these optimizations perform on different CPU architectures?
- How do these optimizations perform with different forest configurations?

Experimental Setup

Approach

- Use a Code-Generator to compile `sklearn` forests (DTs,RF,ET) of varying size to `C-Code`
- Test resulting code + optimizations on 12 datatest on 3 different CPU architectures

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Hardware

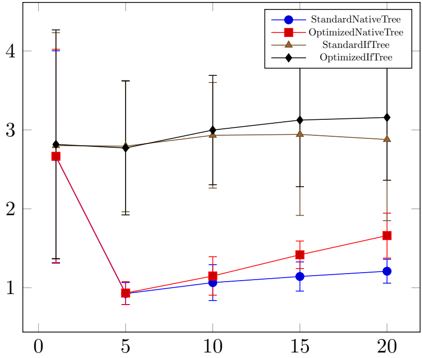
- **X86** Desktop PC with Intel i7-6700 with 16 GB RAM
- **ARM** Raspberry-Pi 2 with ARMv7 and 1GB RAM
- **PPC** NXP Reference Design Board with T4240 processors and 6GB RAM

Experimental Setup (2)

Dataset	# Examples	# Features	Accuracy
adult	8141	64	0.76 - 0.86
bank	10297	59	0.86 - 0.90
covertype	145253	54	0.51 - 0.88
fact	369450	16	0.81 - 0.87
imdb	25000	10000	0.54 - 0.80
letter	5000	16	0.06 - 0.95
magic	4755	10	0.64 - 0.87
mnist	10000	784	0.17 - 0.96
satlog	2000	36	0.40 - 0.90
sensorless	14628	48	0.10 - 0.99
wearable	41409	17	0.57 - 0.99
wine-quality	1625	11	0.49 - 0.68

Results: Desktop PC with Intel (X86)

Note Behaviour similar for DTs, RF and ET → Focus in RF here



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`
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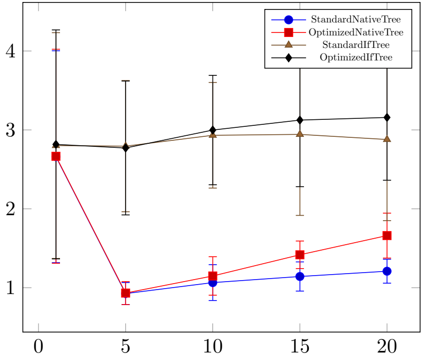

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Take-away On X86 CPUs, `if-else` trees should be favoured

Results: Raspberry Pi with ARMv7 (ARM)

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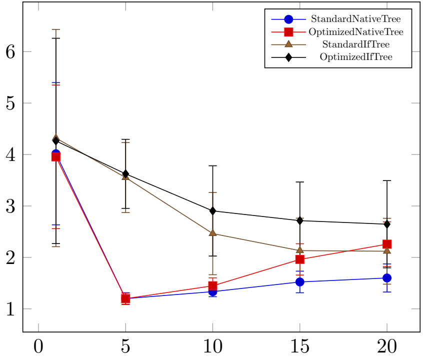

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- Smaller I-Cache (32 KiB) only fits small trees
- Smaller D-Cache (512 KiB) only fits small trees
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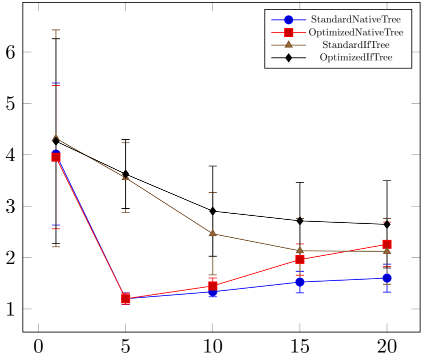

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Take-away Use `if-else` version for small trees. For larger ones there is no clear recommendation

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Our approach Use a code-generator to generate optimized RF code

- There are at-least two ways to implement Decision Trees in modern languages
- `Native` trees mostly rely on the data cache
- `If-else` trees mostly rely on the instruction cache
- Careful cache management can increase performance by 2 – 6 (1500 compared to `sklearn`)
- Optimizations & implementations behave differently on different CPU architectures

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Now Physicist can generate optimized C code for each new experiment

And you as well!

`https://bitbucket.org/sbuschjaeger/arch-forest`