Generating High-Performance General Size Linear Transform Libraries Using Spiral

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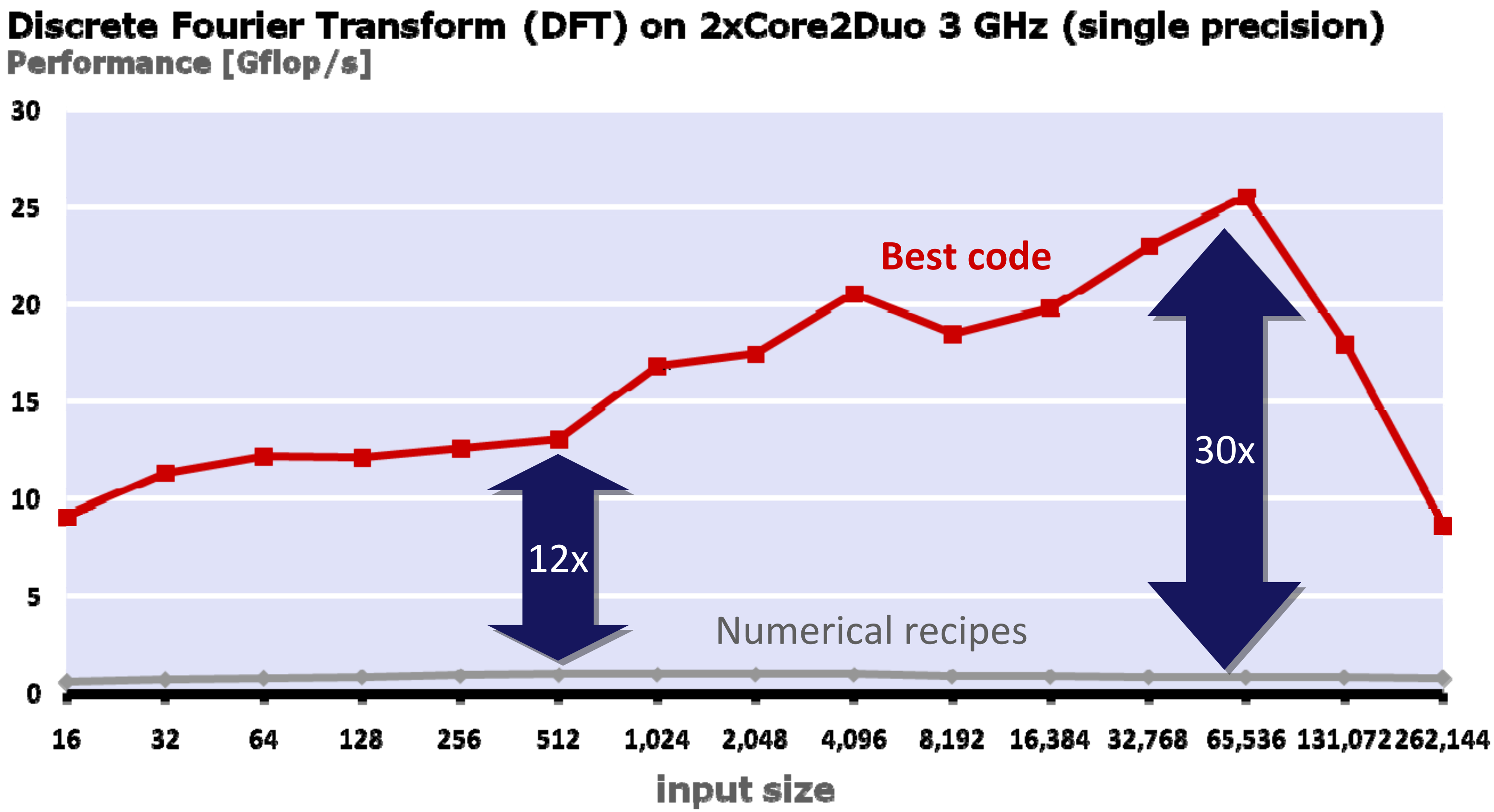
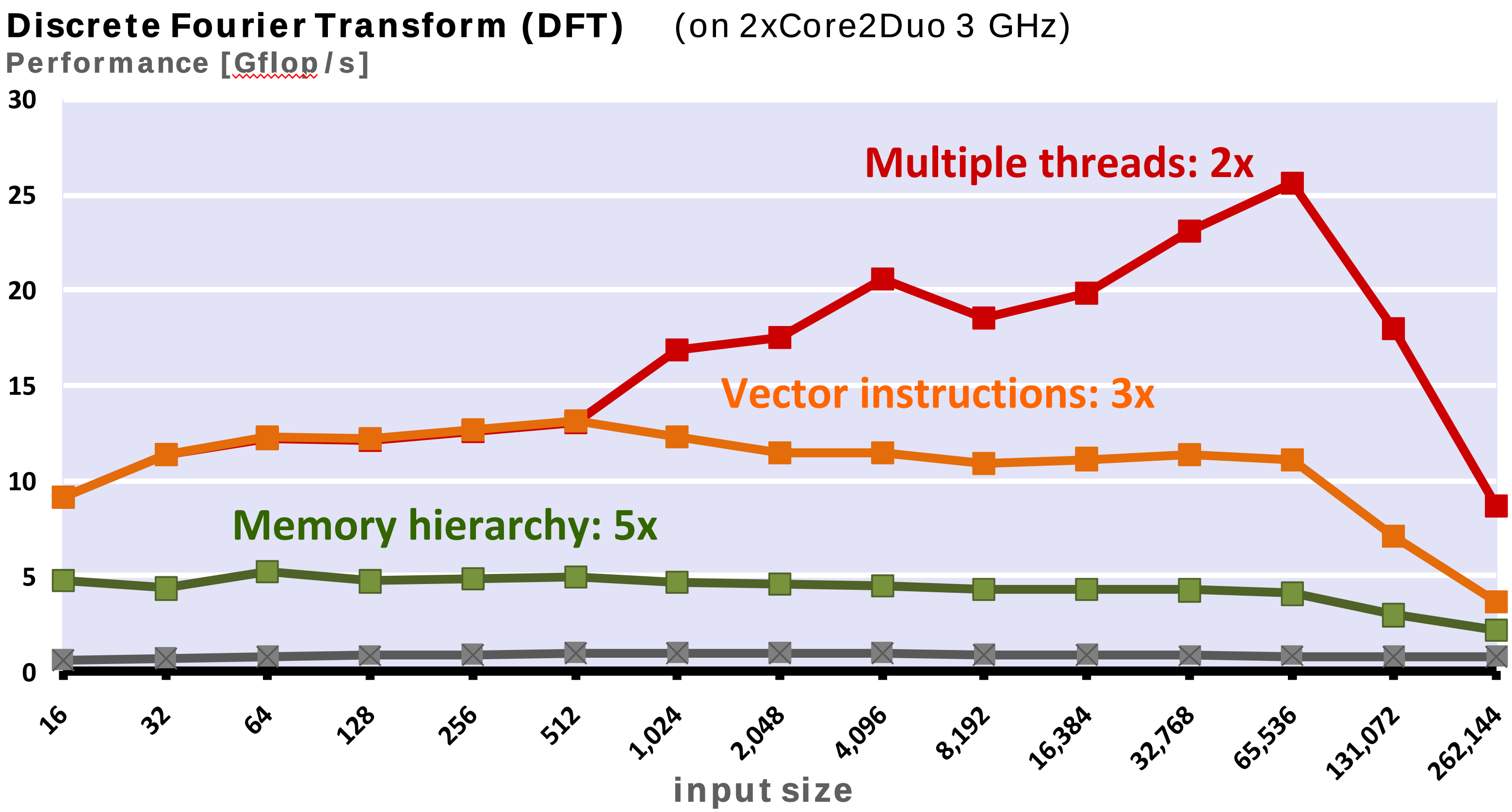
The Problem: Example DFT



- Standard desktop computer
- Same operations count $\approx 4n\log_2(n)$
- *Similar plots can be shown for all numerical problems*

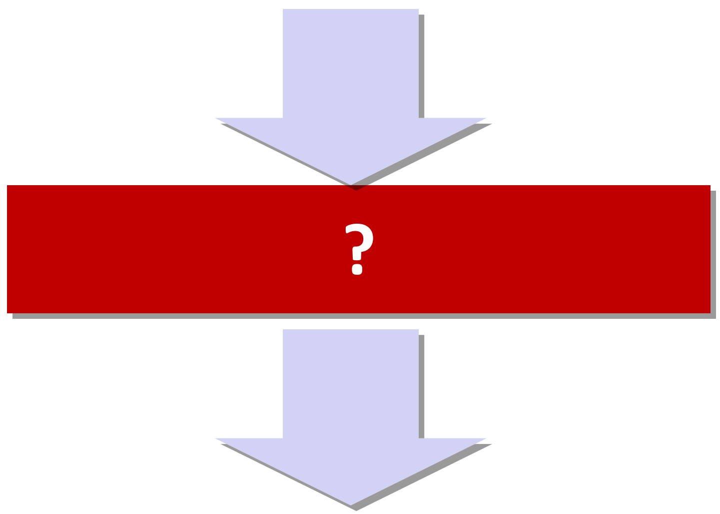
DFT Plot: Analysis



- High performance library development = nightmare
- *Automation?*

Idea: Textbook to Adaptive Library

Textbook FFT

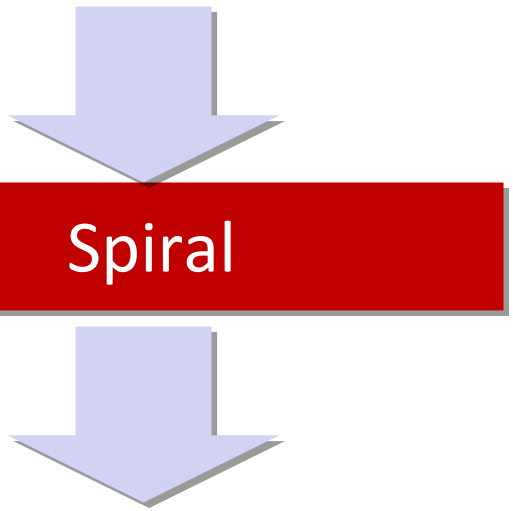


“FFTW”

Goal: Teach Computers to Write Libraries

Input:

- **Transform:** $\mathbf{DFT}_n$
- **Algorithm:** $\mathbf{DFT}_{km} \rightarrow (\mathbf{DFT}_k \otimes I_m) T^{km}_m (I_k \otimes \mathbf{DFT}_m) L^{km}_k$
- **Hardware:** 2-way SIMD + multithreaded



Output:

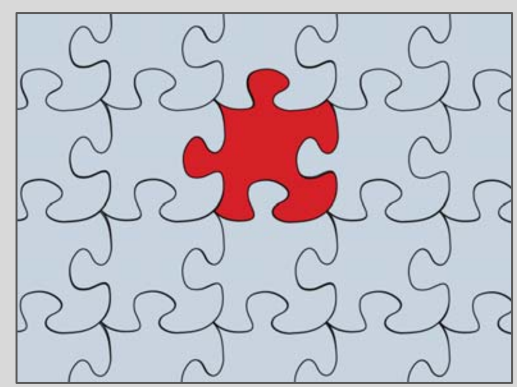
- FFTW equivalent library
- For general input size
- Vectorized and multithreaded
- **Performance competitive**

Key technologies:

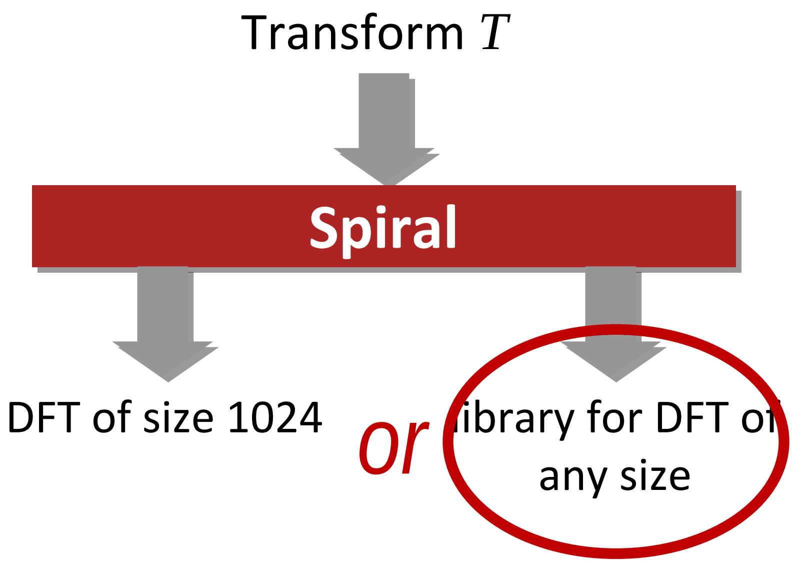
- **Layered domain specific language**
- **Algorithm manipulation via rewriting**
- **Feedback-driven search**

Result:

- **Full automation**



Contribution: General Size Library

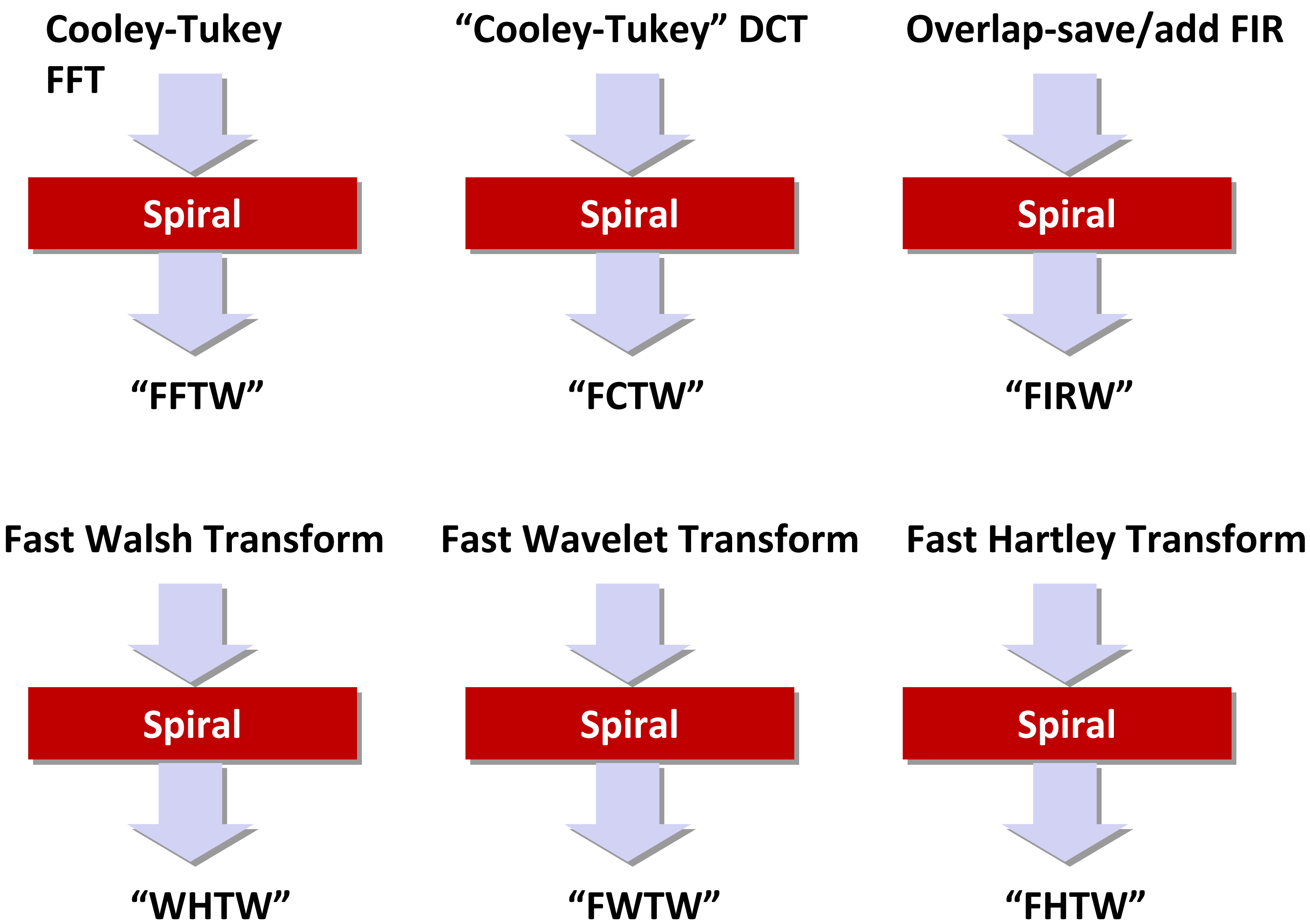



```
dft_1024(X, Y);
```

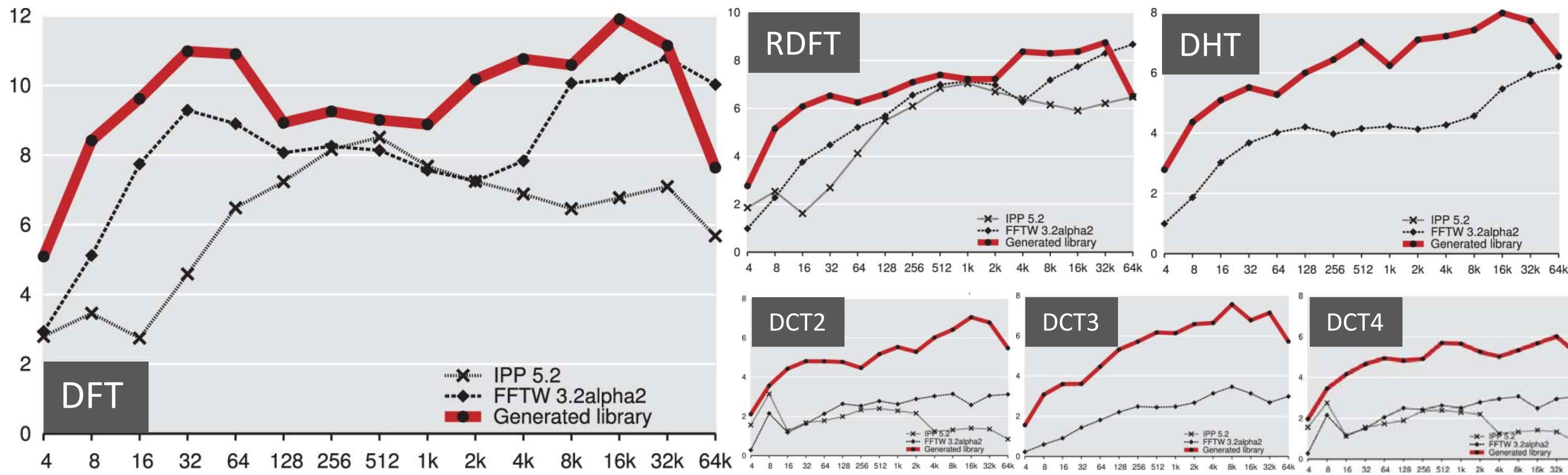
```
Env_1 dft(1024);
dft.compute(X, Y);
```

Fundamentally different problems

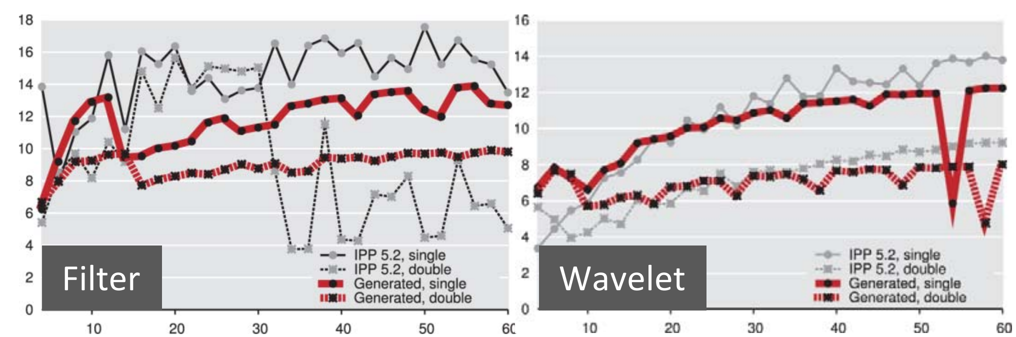
Beyond Fourier Transform and FFTW



Examples of Generated Libraries



- 2-way vectorized, 2-threaded
- Most are faster than hand-written libs
- Code size: 8–120 KLOC or 0.5–5 MB
- Generation time: 1–3 hours



Total: 300 KLOC / 13.3 MB of code generated in < 20 hours
from a few simple algorithm specs

Intel IPP library 6.0 will include Spiral generated code

Linear Transforms

- **Mathematically:** matrix-vector product

$$y = Tx$$

Output vector **Transform matrix** **Input vector**

- **Examples:**

$$\mathbf{DFT}_n = \left[\omega_n^{k\ell}\right]_{0\le k,\ell<n}, \quad \omega_n = e^{-2\pi j/n}$$

$$\mathbf{WHT}_n = \begin{bmatrix} \mathbf{WHT}_{n/2} & \mathbf{WHT}_{n/2} \\ \mathbf{WHT}_{n/2} & -\mathbf{WHT}_{n/2} \end{bmatrix}$$

$$\mathbf{RDFT}_n = \left[\begin{matrix} I''_n \\ \begin{bmatrix} \cos\frac{2\pi k\ell}{n} \\ -\sin\frac{2\pi k\ell}{n} \end{bmatrix} \end{matrix} \right]$$

$$\mathbf{DHT}_n = \left[\begin{matrix} I''_n \\ \begin{bmatrix} \mathrm{cas}\,\frac{2\pi k\ell}{n} \\ \mathrm{cms}\,\frac{2\pi k\ell}{n} \end{bmatrix} \end{matrix} \right]$$

$$\mathbf{DCT\text{-}1}_n = \left[\cos\frac{k\ell\pi}{n-1}\right]$$

$$\mathbf{DST\text{-}1}_n = \left[\sin\frac{(k+1)(\ell+1)\pi}{n+1}\right]$$

$$\mathbf{DCT\text{-}2}_n = \left[\cos\frac{k(2\ell+1)\pi}{2n}\right]$$

$$\mathbf{DST\text{-}2}_n = \left[\sin\frac{(k+1)(2\ell+1)\pi}{2n}\right]$$

$$\mathbf{DCT\text{-}3}_n = \left[\cos\frac{(2k+1)\ell\pi}{2n}\right]$$

$$\mathbf{DST\text{-}3}_n = \left[\sin\frac{(2k+1)(\ell+1)\pi}{2n}\right]$$

$$\mathbf{DCT\text{-}4}_n = \left[\cos\frac{(2k+1)(2\ell+1)\pi}{4n}\right]$$

$$\mathbf{DST\text{-}4}_n = \left[\sin\frac{(2k+1)(2\ell+1)\pi}{4n}\right]$$

$$\mathbf{MDCT}_n = \left[\cos\frac{(2k+1)(2\ell+1+n)\pi}{4n}\right]$$

$$\mathbf{IMDCT}_n = \left[\cos\frac{(2\ell+1)(2k+1+n)\pi}{4n}\right]$$

Fast Algorithms, Example: 4-point FFT

- **Fast algorithms = matrix factorizations**

$$\begin{bmatrix}1 & 1 & 1 & 1\\ 1 & i & -1 & -i\\ 1 & -1 & 1 & -1\\ 1 & -i & -1 & i\end{bmatrix} x \rightarrow \begin{bmatrix}1 & \cdot & 1 & \cdot\\ \cdot & 1 & \cdot & 1\\ 1 & \cdot & -1 & \cdot\\ \cdot & 1 & \cdot & -1\end{bmatrix}\begin{bmatrix}1 & \cdot & \cdot & \cdot\\ \cdot & 1 & \cdot & \cdot\\ \cdot & \cdot & 1 & \cdot\\ \cdot & \cdot & \cdot & i\end{bmatrix}\begin{bmatrix}1 & 1 & \cdot & \cdot\\ 1 & -1 & \cdot & \cdot\\ \cdot & \cdot & 1 & 1\\ \cdot & \cdot & 1 & -1\end{bmatrix}\begin{bmatrix}1 & \cdot & \cdot & \cdot\\ \cdot & \cdot & 1 & \cdot\\ \cdot & 1 & \cdot & \cdot\\ \cdot & \cdot & \cdot & 1\end{bmatrix} x$$

12 adds
4 mults

4 adds

1 mult

4 adds

(when multiplied with input vector {)

$$\mathrm{DFT}_4 \rightarrow (\mathrm{DFT}_2 \otimes \mathrm{I}_2) D (\mathrm{I}_2 \otimes \mathrm{DFT}_2) P$$

Fourier transform Kronecker product Identity Permutation

- **SPL = mathematical, declarative specification**

- **Space of algorithms generated using breakdown rules**

$$\mathrm{DFT}_{mn} \rightarrow (\mathrm{DFT}_m \otimes \mathrm{I}_n) D (\mathrm{I}_m \otimes \mathrm{DFT}_n) P$$

Examples of Breakdown Rules

$$\mathbf{DFT}_n \longrightarrow (\mathbf{DFT}_k \otimes I_m) D_{k,m} (I_k \otimes \mathbf{DFT}_m) L^n_k$$

DFT Cooley-Tukey

$$\mathbf{DFT}_n \longrightarrow V^{-1}_{m,k} (\mathbf{DFT}_k \otimes I_m)(I_k \otimes \mathbf{DFT}_m) V_{m,k} \qquad (2.2)$$

$$\mathbf{DFT}_n \longrightarrow W^{-1}_n (I_1 \oplus \mathbf{DFT}_{n-1}) E_n (I_1 \oplus \mathbf{DFT}_{n-1}) W_n \qquad (2.3)$$

$$\mathbf{DFT}_n \longrightarrow B^\top_{n,m} D_m \, \mathbf{DFT}_m \, D'_m \, \mathbf{DFT}_m \, D''_m B_{n,m}, \quad m \geq 2n-1 \qquad (2.4)$$

$$\mathbf{DFT}_n \longrightarrow P^\top_{k/2,2m} \left(\mathbf{DFT}_{2m} \oplus \left(I_{k/2-1} \otimes_i C_{2m} \, \mathbf{rDFT}_{2m}((i+1)/k)\right)\right) \left(\mathbf{RDFT}'_k \otimes I_m\right) \qquad (2.5)$$

$$\begin{vmatrix} \mathbf{RDFT}_n \\ \mathbf{RDFT}'_n \\ \mathbf{DHT}_n \\ \mathbf{DHT}'_n \end{vmatrix} \longrightarrow (P^\top_{k/2,m} \otimes I_2) \left(\begin{vmatrix} \mathbf{RDFT}_{2m} \\ \mathbf{RDFT}'_{2m} \\ \mathbf{DHT}_{2m} \\ \mathbf{DHT}'_{2m} \end{vmatrix} \oplus \left(I_{k/2-1} \otimes_i M_{2m} \begin{vmatrix} \mathbf{rDFT}_{2m}((i+1)/k) \\ \mathbf{rDFT}_{2m}((i+1)/k) \\ \mathbf{rDHT}_{2m}((i+1)/k) \\ \mathbf{rDHT}_{2m}((i+1)/k) \end{vmatrix} \right) \right)$$

$$\cdot \left(\begin{vmatrix} \mathbf{RDFT}'_k \\ \mathbf{RDFT}'_k \\ \mathbf{DHT}'_k \\ \mathbf{DHT}'_k \end{vmatrix} \otimes I_m \right) \qquad (2.6)$$

$$\mathbf{RDFT}_n \longrightarrow D_n \cdot \mathbf{DCT\text{-}2}_n \cdot P_n, \quad n \text{ odd} \qquad (2.7)$$

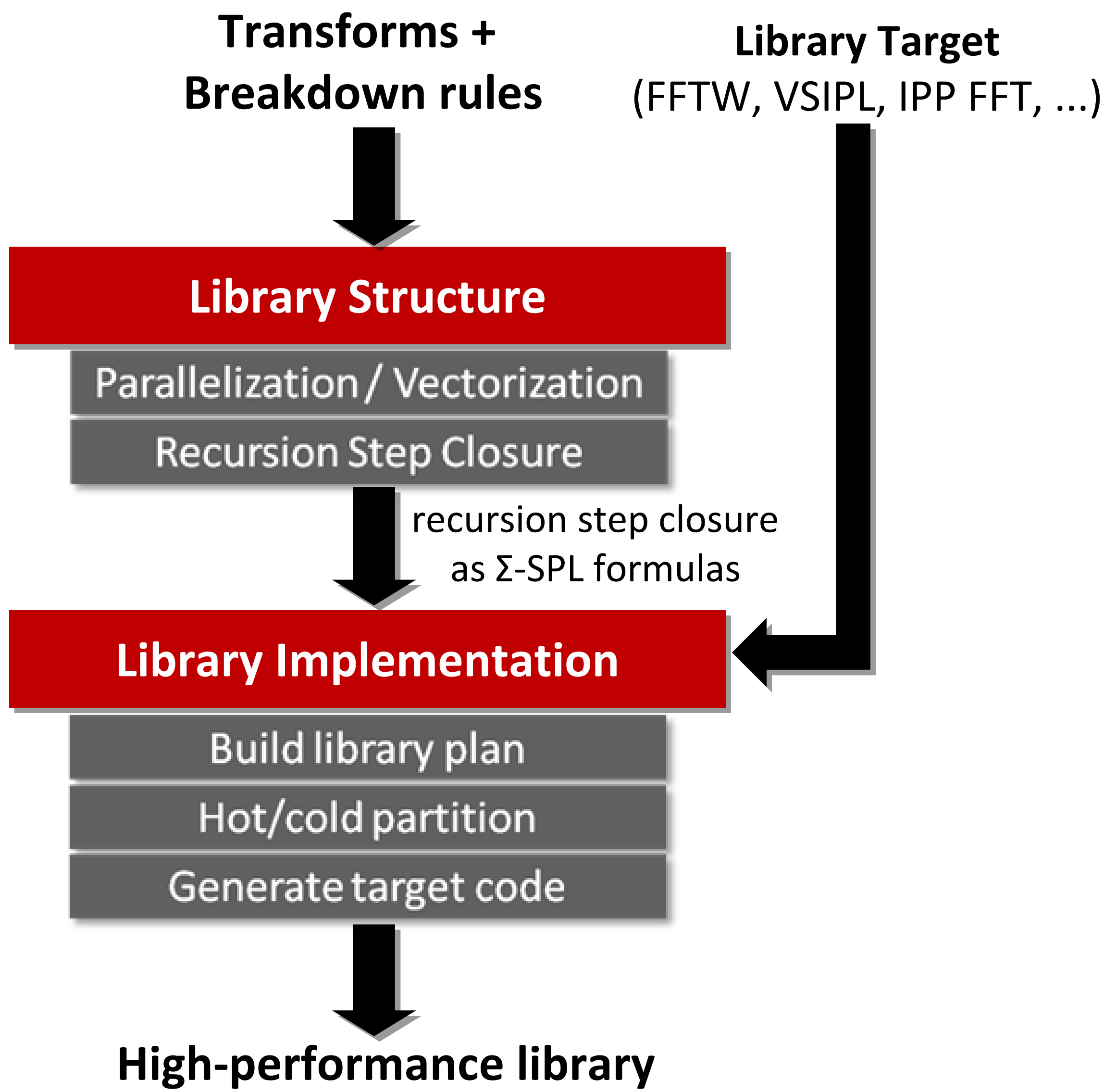
$$\mathbf{DCT\text{-}2}_n \longrightarrow P^\top_{k/2,2m} \left(\mathbf{DCT\text{-}2}_{2m} K^{2m}_2 \oplus \left(I_{k/2-1} \otimes N_{2m} \, \mathbf{RDFT\text{-}3}^\top_{2m}\right)\right) G_n (L^{n/2}_{k/2} \otimes I_2)$$

$$\cdot (I_m \otimes \mathbf{RDFT}'_k) Q_{m/2,k} \qquad (2.8)$$

DCT “Cooley-Tukey”

- “Teach” Spiral domain knowledge of algorithms. Never obsolete.
- Each rule leads to a library

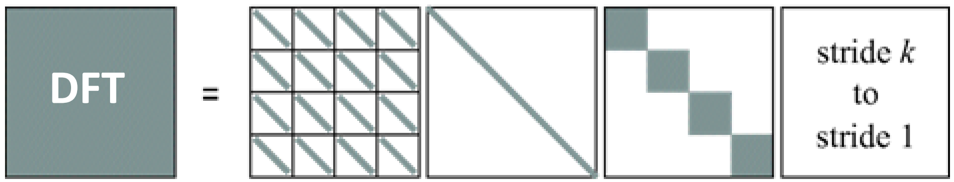
How Library Generation Works



Breakdown Rules to Library Code

- **Cooley-Tukey Fast Fourier Transform (FFT)**

$$\mathrm{DFT}_{km}\, x = (\mathrm{DFT}_k \otimes I_m)\, T_m^{km}\, (I_k \otimes \mathrm{DFT}_m)\, L_k^{km}\, x$$



k=4

- **Naive implementation**

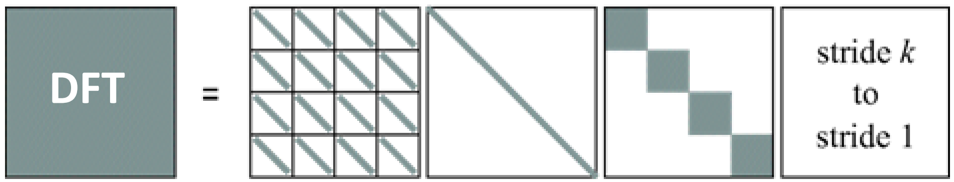
```
void dft(int n, cplx X[], cplx Y[]) {
  k = choose_factor(n); m = n/k;
  Z = permute(X)

  for i=0 to k-1
    dft_subvec(m, Z, Y, …)
  for i=0 to n-1
    Y[i] = Y[i]*T[i];
  for i=0 to m-1
    dft_strided(k, Y, Y, …)
}
```

2 extra functions needed

Breakdown Rules to Library Code

- **Cooley-Tukey Fast Fourier Transform (FFT)**

$$\mathrm{DFT}_{km}\, x = (\mathrm{DFT}_k \otimes I_m) T_m^{km} (I_k \otimes \mathrm{DFT}_m) L_k^{km} x$$



- **Naive implementation**

```
void dft(int n, cplx X[], cplx Y[]) {
  k = choose_factor(n); m = n/k;
  Z = permute(X)

  for i=0 to k-1
    dft_subvec(m, Z, Y, …)
  for i=0 to n-1
    Y[i] = Y[i]*T[i];
  for i=0 to m-1
    dft_strided(k, Y, Y, …)
}
```

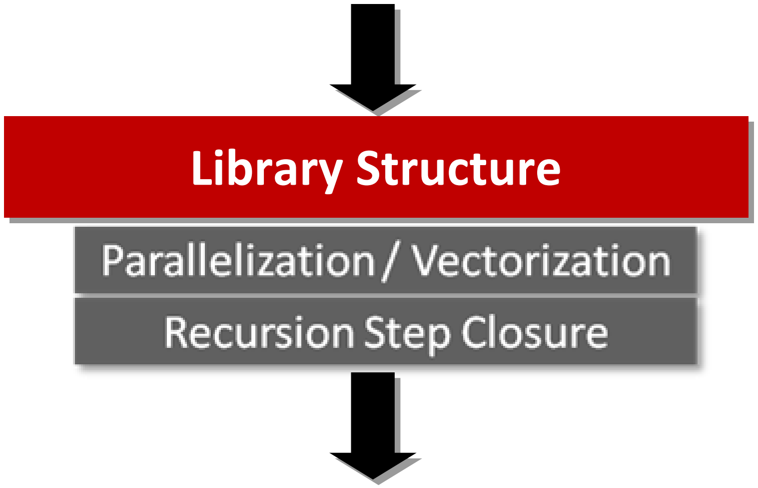
- **Optimized implementation**

```
void dft(int n, cplx X[], cplx Y[]) {
  k = choose_factor(n); m = n/k;

  for i=0 to k-1
    dft_strided2(m, X, Y, …)

  for i=0 to m-1
    dft_strided3_scaled(k, Y, Y, T, …)
}
```

How to discover these specialized variants automatically?

Library Structure

$$V_{k,m}^T(\mathbf{DFT}_k \otimes I_m)(I_k \otimes \mathbf{DFT}_m)\, V_{k,m}$$
$$(\mathbf{DFT}_k \otimes I_m)\, T_m^{km}(I_k \otimes \mathbf{DFT}_m)\, L_k^{km}$$



$$\mathbf{DFT}$$
$$S_z\, \mathbf{DFT}\, G_h$$
$$S_h\, \mathbf{DFT}\, G_z$$
$$S_h\, \mathbf{DFT}\, \mathrm{diag}\,(\mathrm{Dat})\, G_h$$
$$S_h\, \mathbf{DFT}\, G_h$$
$$S_h\, \mathbf{DFT}\, G_{h \circ z}$$
$$S_{h \circ z}\, \mathbf{DFT}\, G_h$$
$$S_h\, \mathbf{DFT}\, \mathrm{diag}\,(\mathrm{Dat})\, G_{h \circ z}$$
$$S_z\, \mathbf{DFT}\, \mathrm{diag}\,(\mathrm{Dat})\, G_h$$
$$S_{h \circ z}\, \mathbf{DFT}\, \mathrm{diag}\,(\mathrm{Dat})\, G_h$$

- **Input:**
  - Breakdown rules
- **Output:**
  - Recursion step closure
  - Σ-SPL Implementation of each recursion step
- **Parallelization/Vectorization**
  - Adds additional breakdown rules
  - Orthogonal to the closure generation

Computing Recursion Step Closure

- **Input:** transform T and a breakdown rule
- **Output:** spawned recursion steps + Σ-SPL implementation
- **Algorithm:**
  1. Apply the breakdown rule
  2. Convert to Σ-SPL
  3. Apply loop merging + index simplification rules.
  4. Extract recursion steps
  5. Repeat until closure is reached

$$\{\mathbf{DFT}_n\}$$

$$\downarrow$$

$$(\{\mathbf{DFT}_{n/k}\} \otimes I_k) T_k^n (I_{n/k} \otimes \{\mathbf{DFT}_k\}) L_{n/k}^n$$

$$\downarrow$$

$$\left(\sum_{i=0}^{k-1} \mathsf{S}_{h_{i,k}} \{\mathbf{DFT}_{n/k}\}\, \mathsf{G}_{h_{i,k}}\right) \mathsf{diag}(f) \left(\sum_{j=0}^{n/k-1} \mathsf{S}_{h_{jk,1}} \{\mathbf{DFT}_k\}\, \mathsf{G}_{h_{jk,1}}\right) \mathsf{perm}(\ell_{n/k}^n)$$

$$\downarrow$$

$$\sum_{i=0}^{k-1} \mathsf{S}_{h_{i,k}} \{\mathbf{DFT}_{n/k}\}\, \mathsf{diag}(f \circ h_{i,k})\, \mathsf{G}_{h_{i,k}} \sum_{j=0}^{n/k-1} \mathsf{S}_{h_{jk,1}} \{\mathbf{DFT}_k\}\, \mathsf{G}_{h_{j,n/k}}$$

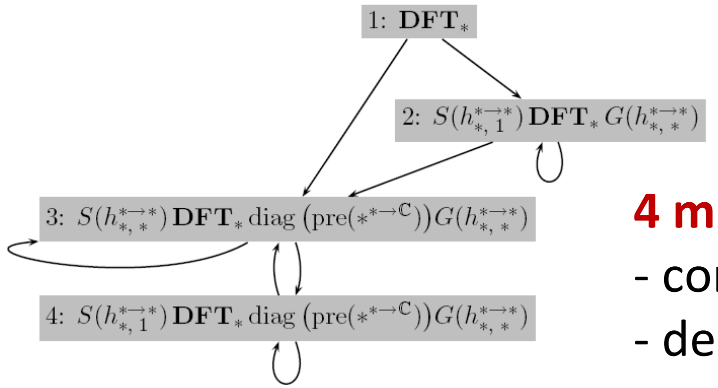
$$\downarrow$$

$$\sum_{i=0}^{k-1} \boxed{\left\{ \mathsf{S}_{h_{i,k}}\, \mathbf{DFT}_{n/k}\, \mathsf{diag}(f \circ h_{i,k})\, \mathsf{G}_{h_{i,k}} \right\}} \sum_{j=0}^{n/k-1} \boxed{\left\{ \mathsf{S}_{h_{jk,1}}\, \mathbf{DFT}_k\, \mathsf{G}_{h_{j,n/k}} \right\}}$$

Parametrization (not shown) derives the independent parameter set for each recursion step

Recursion Step Closure Examples

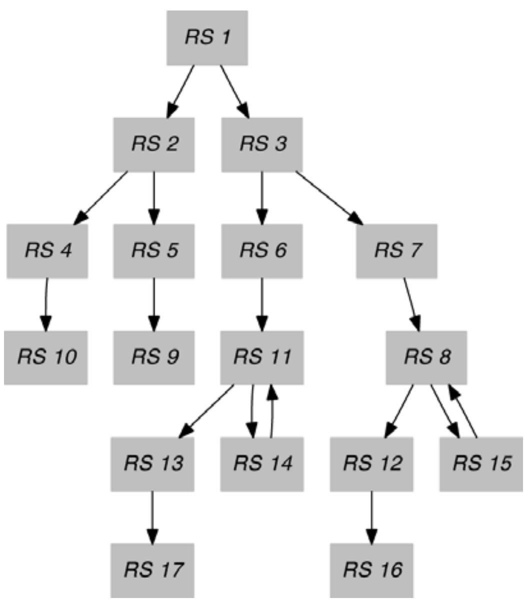
DFT (scalar)



4 mutually recursive functions

- computed automatically
- described using Σ-SPL formulas

DCT4 (vectorized)



1 : $\mathrm{Vec}_2(\mathbf{DCT\text{-}4}_{u_1})$

2 : $\mathrm{Vec}_2(\mathrm{GT}(\mathrm{diag}\,(N_{2u_8})\,\mathbf{RDFT\text{-}3}^{\top}_{2u_8}\,\mathrm{rcdiag}(\mathrm{pre}({u_4}^{\mathbb{Z}\times 2u_8\to\mathbb{R}})),\ h^{2u_8\to u_6}_{0,\,1,u_7}\circ \ell^{2u_8}_{u_8},\ r^{2u_8\to u_9}_{0,\,u_{11},1,\,u_{12}},\ \{u_{13}\}))$

3 : $\mathrm{Vec}_2(\mathrm{GT}(\mathbf{RDFT\text{-}3}_{u_1}\,\mathrm{diag}\,(N_{u_1}),\ r^{u_1\to u_3}_{0,\,u_5,1,\,u_6},\ h^{u_1\to u_8}_{0,\,u_9,1},\ \{u_{10}\}))$

4 : $\mathrm{VJam}_2(\mathrm{GT}(\mathrm{diag}\,(N_{2u_9})\,\mathbf{RDFT\text{-}3}^{\top}_{2u_9}\,\mathrm{rcdiag}(\mathrm{pre}({u_4}^{\mathbb{Z}\times\mathbb{Z}\times 2u_9\to\mathbb{R}})),\ h^{2u_9\to u_6}_{0,\,1,u_7,u_8}\circ \ell^{2u_9}_{u_9},\ r^{2u_9\to u_{10}}_{0,\,u_{12},1,2,\,u_{13}},\ \{2,u_{14}\}))$

5 : $\mathrm{GT}(\mathrm{diag}\,(N_{2u_9})\,\mathbf{RDFT\text{-}3}^{\top}_{2u_9}\,\mathrm{rcdiag}(\mathrm{pre}({u_4}^{\mathbb{Z}\times 2u_9\to\mathbb{R}})),\ h^{2u_9\to u_6}_{u_7,\,1,u_8}\circ \ell^{2u_9}_{u_9},\ r^{2u_9\to u_{10}}_{u_{12},\,u_{13},1,\,u_{14}},\ \{u_{15}\})$

6 : $\mathrm{VJam}_2(\mathrm{GT}(\mathbf{RDFT\text{-}3}_{u_1}\,\mathrm{diag}\,(N_{u_1}),\ r^{u_1\to u_3}_{0,\,u_5,1,2,\,u_6},\ h^{u_1\to u_8}_{0,\,u_9,1,2},\ \{2,u_{10}\}))$

7 : $\mathrm{GT}(\mathbf{RDFT\text{-}3}_{u_1}\,\mathrm{diag}\,(N_{u_1}),\ r^{u_1\to u_3}_{u_5,\,u_6,1,\,u_7},\ h^{u_1\to u_9}_{u_{10},\,u_{11},1},\ \{u_{12}\})$

8 : $\mathrm{S}(h^{u_1\to u_2}_{u_3,\,u_4})\,\mathbf{RDFT\text{-}3}_{u_1}\,\mathrm{diag}\,(N_{u_1})\mathrm{G}(r^{u_1\to u_7}_{u_9,\,u_{10},\,u_{11}})$

9 : $\mathrm{S}(r^{2u_{13}\to u_1}_{u_3,\,u_4,\,u_5})\mathrm{diag}\,(N_{2u_{13}})\,\mathbf{RDFT\text{-}3}^{\top}_{2u_{13}}\,\mathrm{rcdiag}(\mathrm{pre}({u_9}^{2u_{13}\to\mathbb{R}}))\mathrm{G}(h^{2u_{13}\to u_{11}}_{u_{12},\,1}\circ \ell^{2u_{13}}_{u_{13}})$

10 : $\mathrm{VJam}_2(\mathrm{GT}(\mathrm{diag}\,(N_{2u_9})\,\mathbf{RDFT\text{-}3}^{\top}_{2u_9}\,\mathrm{rcdiag}(\mathrm{pre}({u_4}^{\mathbb{Z}\times 2u_9\to\mathbb{R}})),\ h^{2u_9\to u_6}_{u_7,\,1,u_8}\circ \ell^{2u_9}_{u_9},\ r^{2u_9\to u_{10}}_{u_{12},\,u_{13},1,\,u_{14}},\ \{2\}))$

11 : $\mathrm{VJam}_2(\mathrm{GT}(\mathbf{RDFT\text{-}3}_{u_1}\,\mathrm{diag}\,(N_{u_1}),\ r^{u_1\to u_3}_{u_5,\,u_6,1,\,u_7},\ h^{u_1\to u_9}_{u_{10},\,u_{11},1},\ \{2\}))$

12 : $\mathrm{GT}(\mathrm{diag}\,(C_{u_1})\,\mathbf{rDFT}_{2u_1}(\lambda\text{-wrap}({\lambda_1}^{\mathbb{Z}\times\mathbb{Z}\to\mathbb{R}})),\ h^{2u_1\to u_4}_{0,\,1,u_5},\ h^{2u_{10}\to u_7}_{u_8,\,u_9}\circ(r^{u_1\to u_{10}}_{0,\,u_{12},1,\,u_{13}}\otimes \imath_2),\ \{u_{14}\})$

13 : $\mathrm{VJam}_2(\mathrm{GT}(\mathrm{diag}\,(C_{u_1})\,\mathbf{rDFT}_{2u_1}(\lambda\text{-wrap}({\lambda_1}^{\mathbb{Z}\times\mathbb{Z}\times\mathbb{Z}\to\mathbb{R}})),\ h^{2u_1\to u_4}_{u_5,\,u_6,1,u_7},\ h^{2u_{12}\to u_9}_{u_{10},\,u_{11},1}\circ(r^{u_1\to u_{12}}_{0,\,u_{14},0,1,\,u_{15}}\otimes \imath_2),\ \{2,u_{16}\}))$

14 : $\mathrm{VJam}_2(\mathrm{GT}(\mathbf{RDFT\text{-}3}_{u_1}\,\mathrm{diag}\,(N_{u_1}),\ r^{u_1\to u_3}_{u_5,\,u_6,1,u_7,\,u_8},\ h^{u_1\to u_{10}}_{u_{11},\,u_{12},1,u_{13}},\ \{2,u_{14}\}))$

15 : $\mathrm{GT}(\mathbf{RDFT\text{-}3}_{u_1}\,\mathrm{diag}\,(N_{u_1}),\ r^{u_1\to u_3}_{u_5,\,u_6,u_7,\,u_8},\ h^{u_1\to u_{10}}_{0,\,u_{11},1},\ \{u_{12}\})$

16 : $\mathrm{S}(h^{2u_5\to u_2}_{u_3,\,u_4}\circ(r^{u_6\to u_5}_{u_7,\,u_8,\,u_9}\otimes \imath_2))\mathrm{diag}\,(C_{u_6})\,\mathbf{rDFT}_{2u_6}(\lambda\text{-wrap}({\lambda_1}^{\mathbb{Z}\to\mathbb{R}}))\mathrm{G}(h^{2u_6\to u_{13}}_{u_{14},\,1})$

17 : $\mathrm{VJam}_2(\mathrm{GT}(\mathrm{diag}\,(C_{u_1})\,\mathbf{rDFT}_{2u_1}(\lambda\text{-wrap}({\lambda_1}^{\mathbb{Z}\times\mathbb{Z}\to\mathbb{R}})),\ h^{2u_1\to u_4}_{u_5,\,u_6,1},\ h^{2u_{11}\to u_8}_{u_9,\,u_{10},1}\circ(r^{u_1\to u_{11}}_{u_{13},\,u_{14},\,u_{15}}\otimes \imath_2),\ \{2\}))$

17 mutually recursive functions

Base Cases

- **Base cases are called "codelets" in FFTW**
- **Why needed:**
  - Closure is converted into mutually recursive functions
  - Recursion must be terminated
  - Larger base cases eliminate overhead from recursion
- **How many:**
  - **In FFTW 3.2:** 183 codelets for complex DFT (21 types)
    147 codelets for real DFT (18 types)
  - **In our generator:** # codelet types ‰ # recursion steps
- **Obtained by using standard Spiral to generate fixed size code**

$$\left\{\mathrm{S}(h_{u_3,1}^{2\rightarrow u_2})\,\mathbf{DFT}_2\,\mathrm{G}(h_{u_7,u_8}^{2\rightarrow u_6})\right\}$$
$$\left\{\mathrm{S}(h_{u_3,1}^{3\rightarrow u_2})\,\mathbf{DFT}_3\,\mathrm{G}(h_{u_7,u_8}^{3\rightarrow u_6})\right\}$$
$$\ldots$$

Library Implementation

$$\begin{array}{c}
\mathbf{DFT} \\
S_z\, \mathbf{DFT}\, G_h \\
S_h\, \mathbf{DFT}\, G_z \\
S_h\, \mathbf{DFT}\, \mathrm{diag}\,(\mathrm{Dat})\, G_h \\
S_h\, \mathbf{DFT}\, G_h \\
S_h\, \mathbf{DFT}\, G_{h\circ z} \\
S_{h\circ z}\, \mathbf{DFT}\, G_h \\
S_h\, \mathbf{DFT}\, \mathrm{diag}\,(\mathrm{Dat})\, G_{h\circ z} \\
S_z\, \mathbf{DFT}\, \mathrm{diag}\,(\mathrm{Dat})\, G_h \\
S_{h\circ z}\, \mathbf{DFT}\, \mathrm{diag}\,(\mathrm{Dat})\, G_h
\end{array}$$

Library Implementation

Build library plan

Hot/cold partition

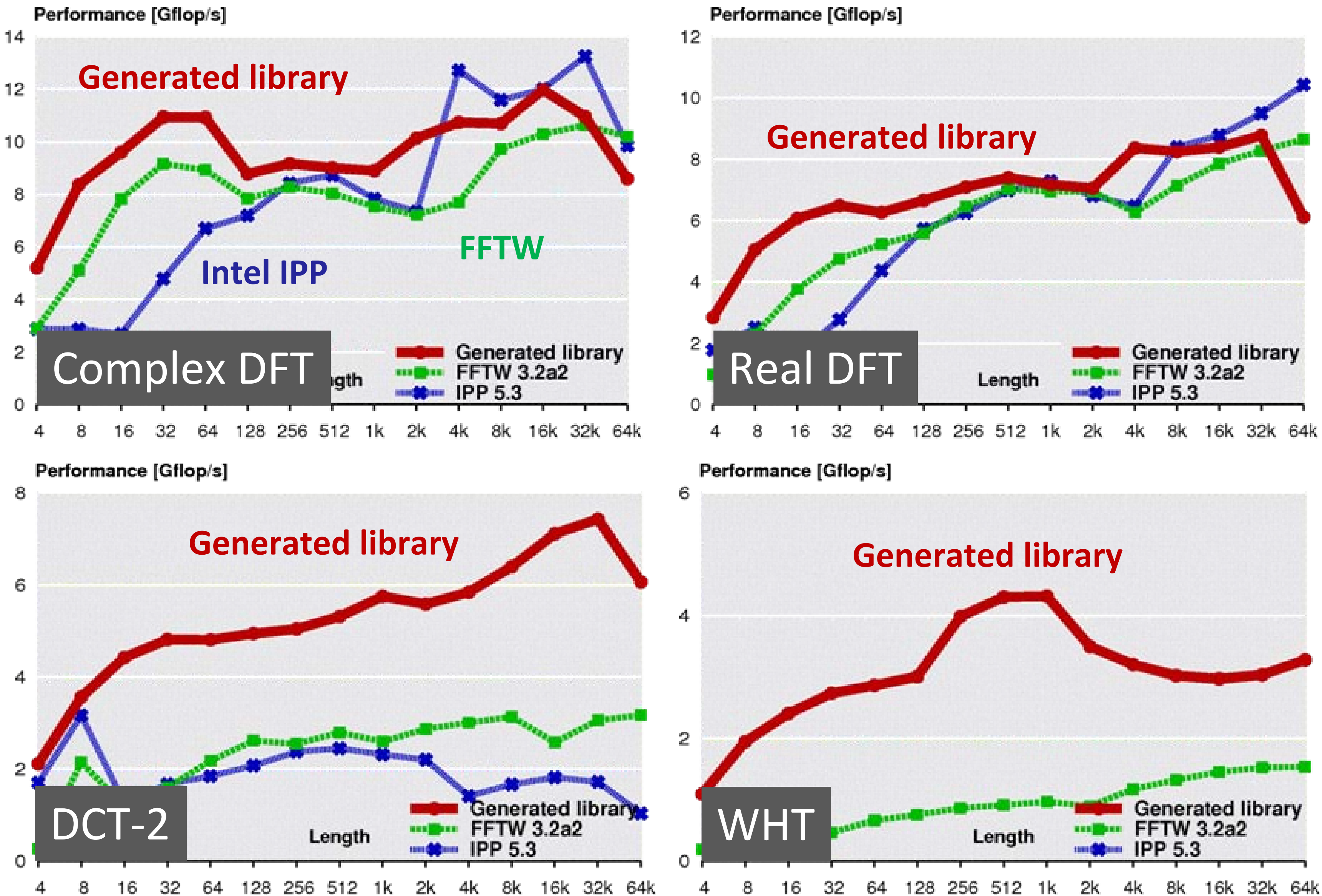
Generate target code

High-performance library

- **Input:**
  - Recursion step closure
  - Σ-SPL implementation of each recursion step
    (base cases + recursions)
- **Output:**
  - High-performance library
  - Target language: C++, Java, etc.
- **Process:**
  - Build library plan
  - Perform hot/cold partitioning
  - Generate target language code

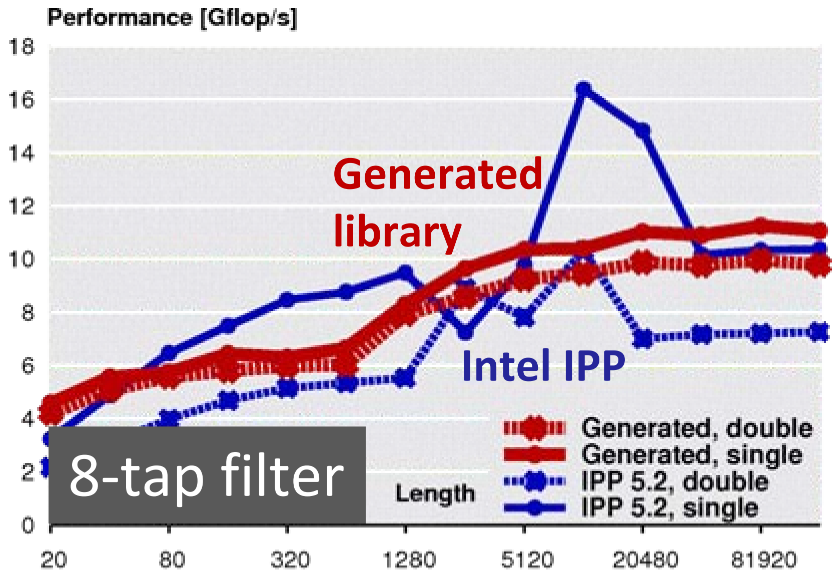
Double Precision Performance: Intel Xeon 5160

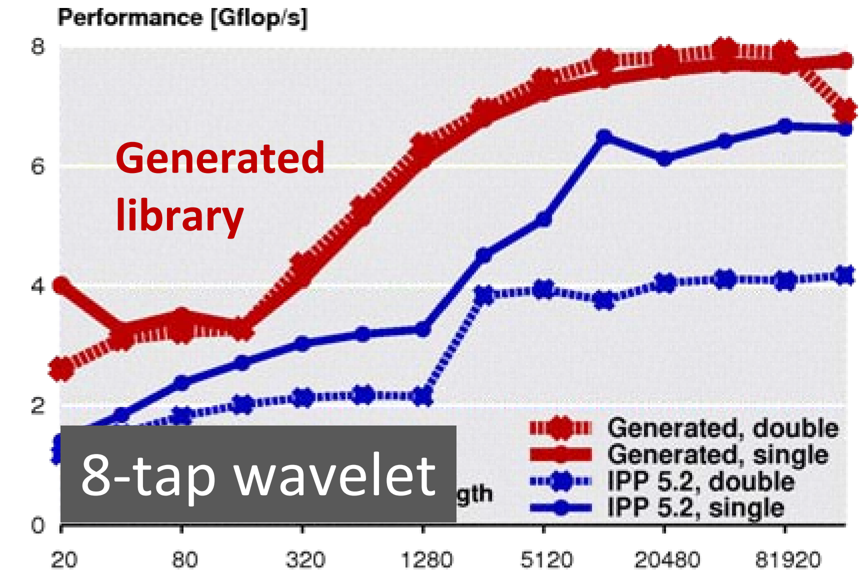
2-way vectorization, up to 2 threads

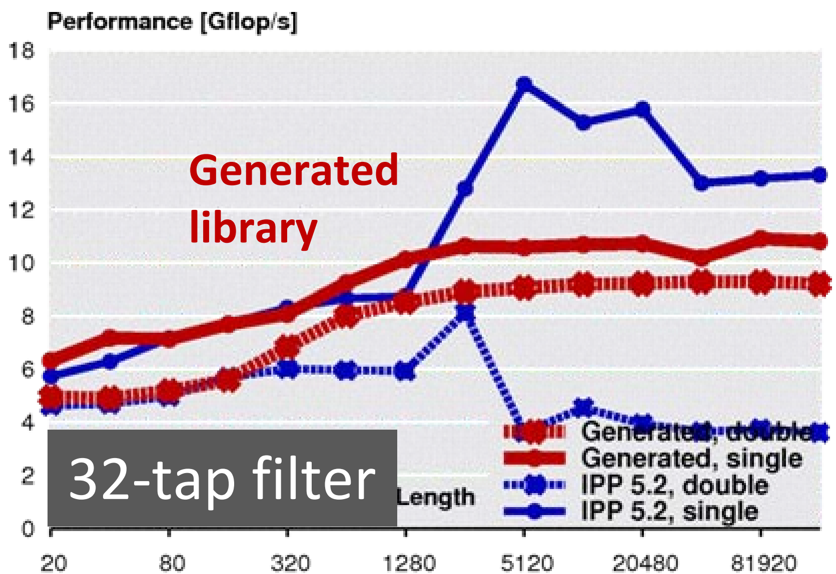


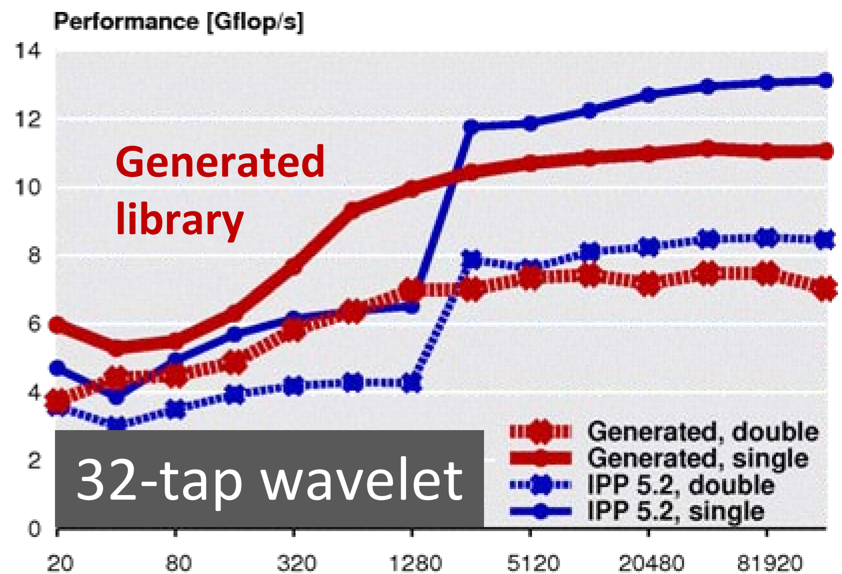
FIR Filter Performance

2- and 4-way vectorization, up to 2 threads



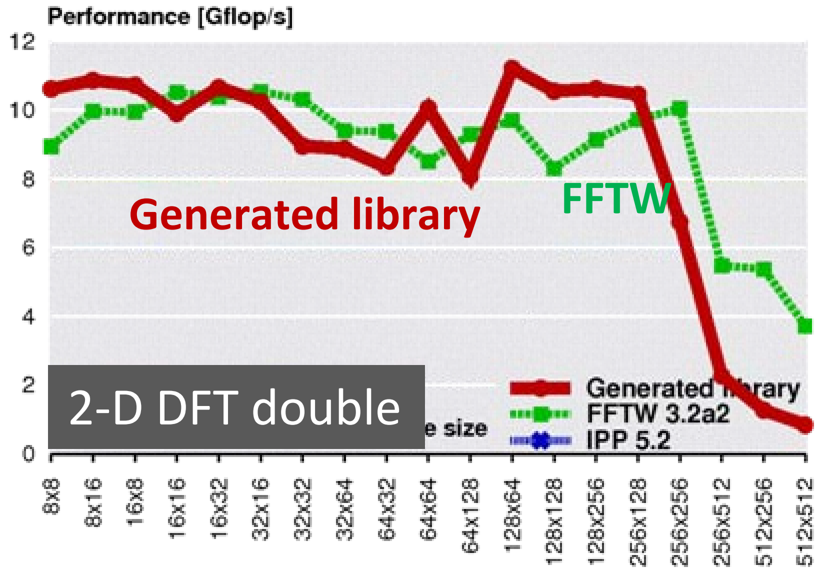


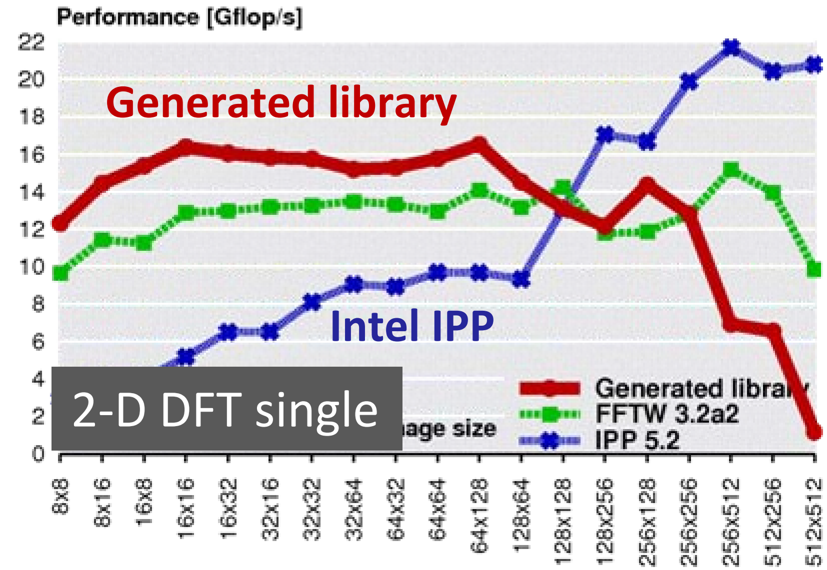


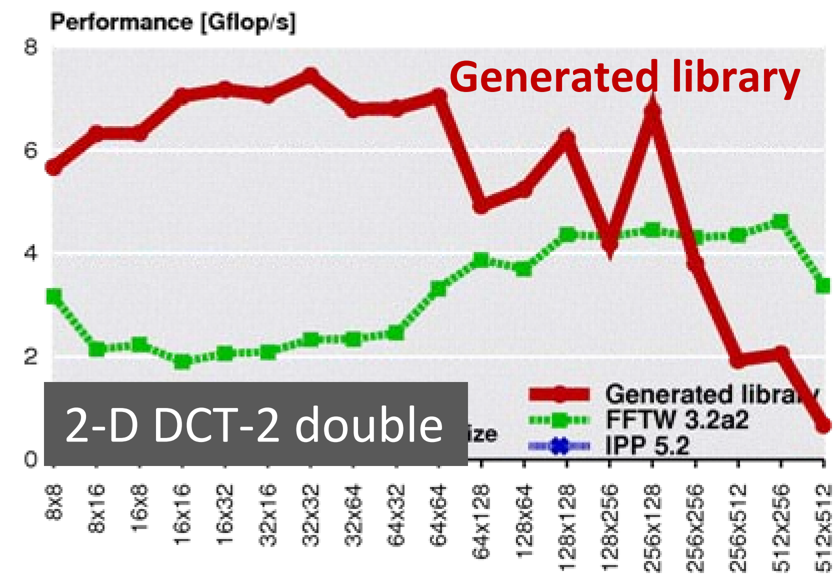


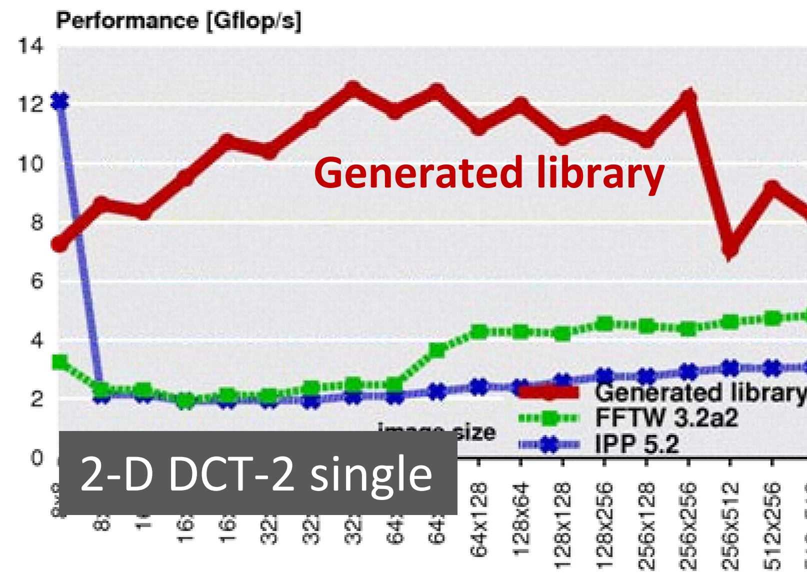
2-D Transforms Performance

2- or 4-way vectorization, up to 2 threads

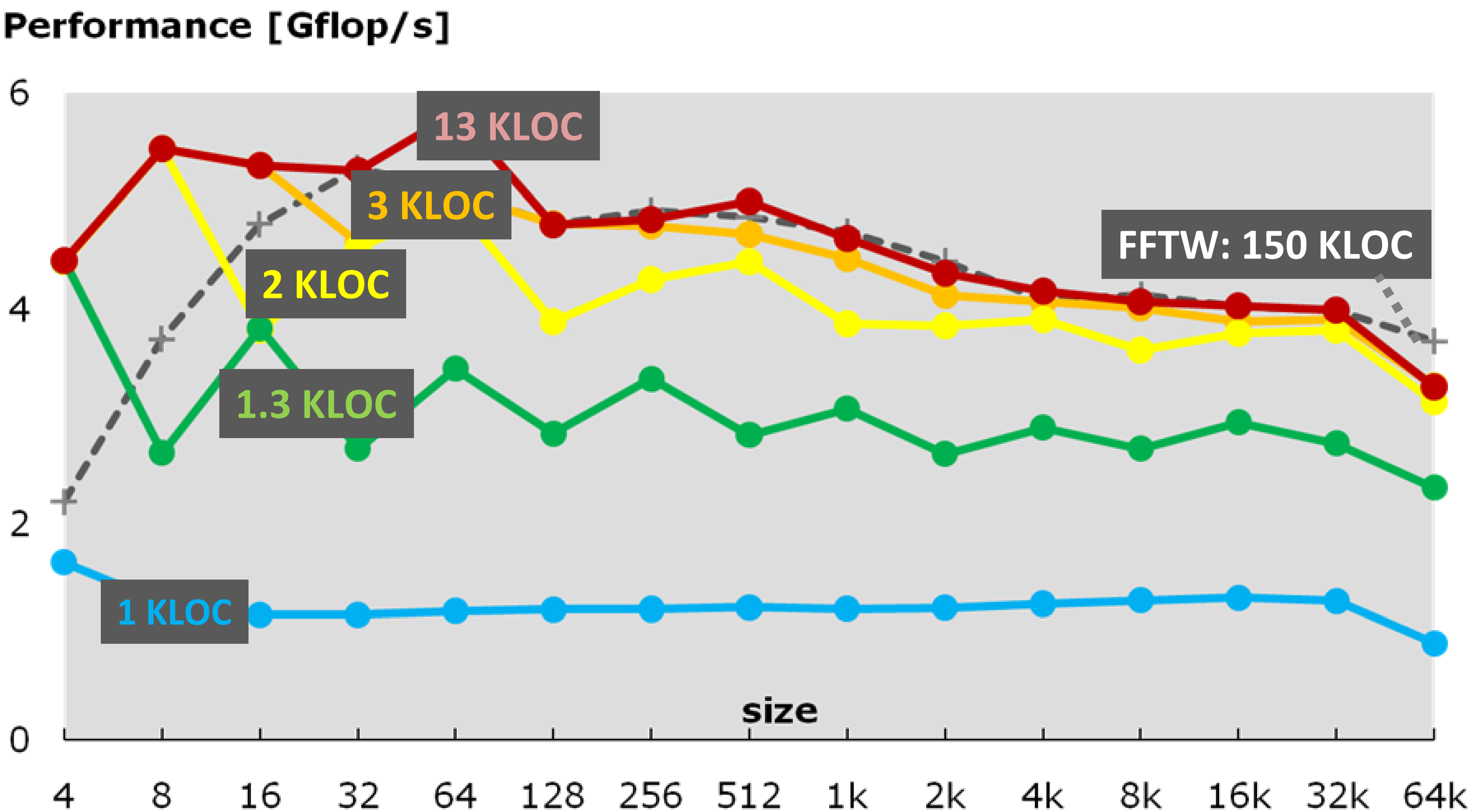




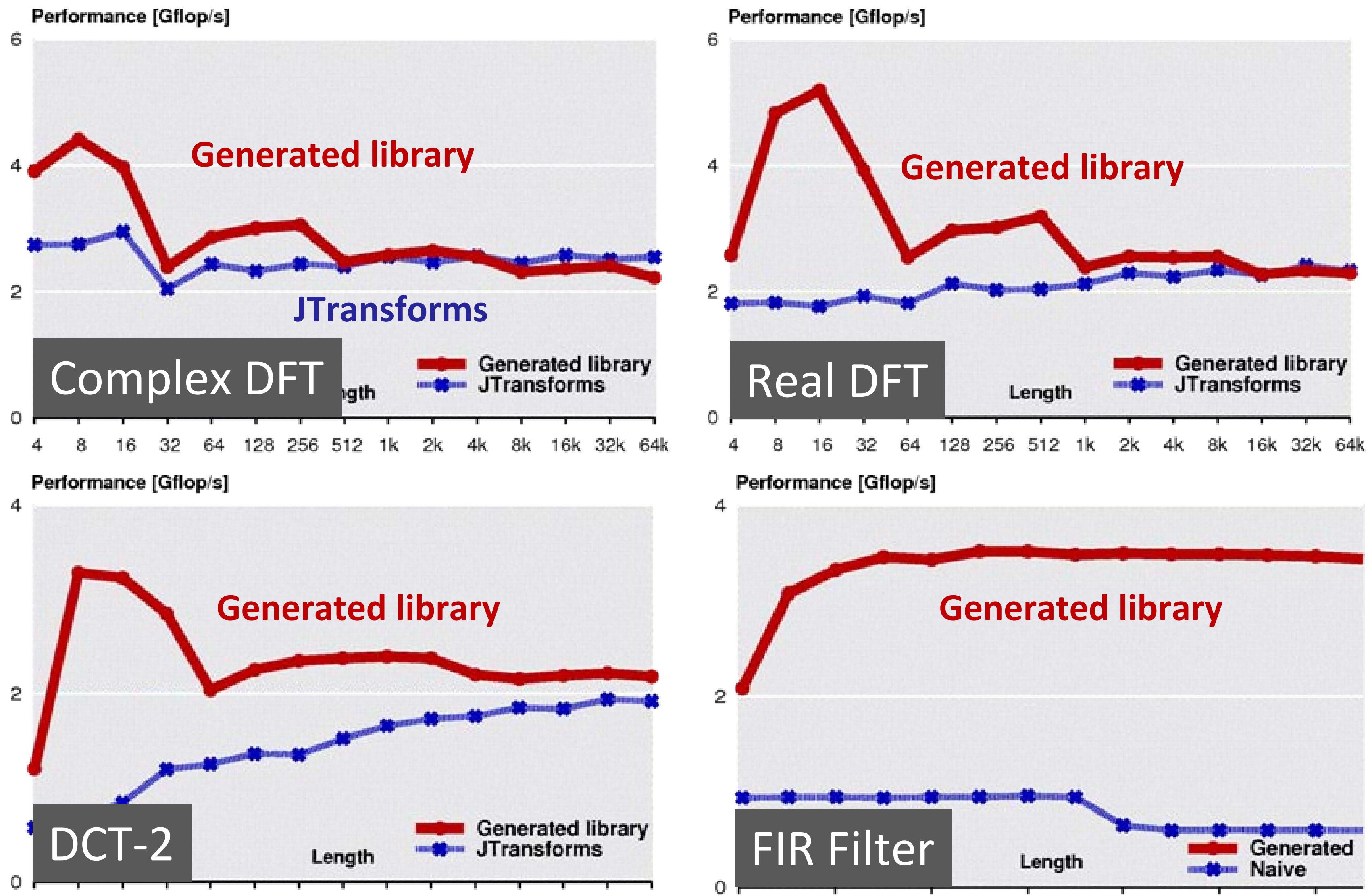




Customization: Code Size



Backend Customization: Java



Portable, but only 50% of scalar C performance

Summary

- **Full automation:**
  Textbook to adaptive library
- **Performance**
  - SIMD
  - Multicore
- **Customization**
- **Industry collaboration**
  - Intel IPP 6.0 will include Spiral generated code