Package: zufft (via r-universe)

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Title Fast Fourier, Cosine and Sine Transforms

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Description Computes discrete Fourier transforms (complex, real-to-complex and complex-to-real) and discrete cosine and sine transforms of types one to four over any axes of an array, with the fast Fourier transform (FFT) code of 'ducc0' (<https://github.com/mreineck/ducc>) bundled in the BSD-licensed subset that 'SciPy' uses. Transforms of any length run in O(n log n) time, real input uses true real transforms, and several threads can share one transform.

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`fft_c2c` *Discrete Fourier transforms*

Description

`fft_c2c()` computes the complex discrete Fourier transform of `x` or its inverse, `fft_r2c()` the transform of real input keeping only the non-redundant half of the last transformed axis, and `fft_c2r()` the inverse of `fft_r2c()`, returning real values. All three work over any subset of the dimensions of an array, in O(n log n) time for every length.

Usage

```
fft_c2c(
  x,
  inverse = FALSE,
  n = NULL,
  axes = NULL,
  norm = c("backward", "ortho", "forward", "none"),
  workers = NULL
)

fft_r2c(
  x,
  n = NULL,
  axes = NULL,
  norm = c("backward", "ortho", "forward", "none"),
  workers = NULL
)

fft_c2r(
  x,
  n = NULL,
  axes = NULL,
  norm = c("backward", "ortho", "forward", "none"),
  workers = NULL
)
```

Arguments

- `x` — A double, integer, logical or complex vector or array. Integer and logical values are converted to double. `fft_r2c()` needs real input; `fft_c2r()` treats real input as complex.
- `inverse` — `TRUE` for the inverse transform. `0` and `1` are accepted too, as in fftwtools.
- `n` — Transform lengths, one per transformed axis in the order of `axes` (no recycling); with `axes = NULL`, one per dimension, in dimension order. Each axis of `x` is cropped or zero-padded to its length first. `NULL` keeps the lengths of `x`. For `fft_c2r()`, `n` gives the lengths of the real output; the halved axis of `x` must then hold `n %/% 2 + 1` values and is cropped or padded to that. Its default is `2 * (m - 1)` for an input extent `m`, which is always even: give `n` to recover an odd length.
- `axes` — The dimensions to transform, 1-based, without repeats. `NULL` means all of them, in order; for `fft_r2c()` and `fft_c2r()` it means all of them in reverse order, so the first dimension is halved. With explicit `axes`, the real transforms halve the last axis listed, as SciPy does: `axes = seq_along(dim(x))` halves the last dimension. Use `axes = 1` for a column-wise transform of a matrix, as `stats::mvfft()` does.
- `norm` — Where the scaling goes. `"backward"` (the default) leaves the forward transform unscaled and divides the inverse by `N`, the product of the transformed lengths; `"forward"` does the opposite; `"ortho"` divides both by `sqrt(N)`; `"none"` scales neither direction, as FFTW, fftwtools and `stats::fft()` do.
- `workers` — Threads to use. `NULL` uses the session default (1). Negative values count back from the number of available cores: `-1` means all of them. Requests are capped at the available cores, and at 2 when `_R_CHECK_LIMIT_CORES_` is set. Threads split the independent 1-D transforms of a multi-dimensional array, so they help only arrays with at least 32 768 elements and more than one line. Results agree to rounding whatever the number of threads; they are bit-identical on builds without fused multiply-add (CRAN's x86-64 builds).

Details

The conventions are those of `scipy.fft` (`fft`, `fftn`, `rfftn`, `irfftn`): `n` crops or zero-pads each transformed axis before the transform, and `norm` chooses where the scaling goes. They differ from SciPy in three ways: `axes` are 1-based; `axes = NULL` means every dimension rather than the last one; and with `axes = NULL` the real transforms halve the *first* dimension, not the last. R stores arrays column by column, so the first dimension is the contiguous one, and halving it is the fast choice (about 1.8 times faster than halving the last for a 2048 x 2048 matrix). It is also what fftwtools' 2-D and 3-D real transforms do.

Coming from fftwtools: `fft_c2c(x)` is `fftw(x)` and `fftw_r2c(x)`, `fft_r2c(x)` is `fftw_r2c(x, HermConj = 0)`, and an fftwtools inverse is the zufft inverse with `norm = "none"`, because fftwtools, like `stats::fft()`, never scales.

Value

For `fft_c2c()` and `fft_r2c()` a complex vector or array, for `fft_c2r()` a double one. Arrays keep their `dim`, with the transformed extents, and the `dimnames` of axes that were not transformed; `names` are dropped.

See Also

stats::fft() for R's own complex transform.

Other transforms: fft_dct()

Examples

```
x <- c(1, 2, 3, 4, 3, 2)
fft_c2c(x)
fft_r2c(x)
fft_c2r(fft_r2c(x), n = length(x))

# an inverse that matches fftwtools and stats::fft(inverse = TRUE)
fft_c2c(fft_c2c(x), inverse = TRUE, norm = "none") / length(x)

# columns of a matrix, and both axes
m <- matrix(rnorm(12), 4, 3)
fft_c2c(m, axes = 1)
dim(fft_r2c(m))                # halves the first dimension: 3 x 3
dim(fft_r2c(m, axes = 1:2))    # SciPy's choice, the last: 4 x 2
fft_c2r(fft_r2c(m), n = dim(m)) # back to m
```

---

fft_dct *Discrete cosine and sine transforms*

Description

fft_dct() and fft_dst() compute discrete cosine and sine transforms of types 1 to 4, or their inverses, over any subset of the dimensions of an array. The definitions, scaling and orthogonalize behaviour are those of scipy.fft.dct(), dctn(), dst() and dstn().

Usage

```
fft_dct(
  x,
  type = 2L,
  inverse = FALSE,
  n = NULL,
  axes = NULL,
  norm = c("backward", "ortho", "forward", "none"),
  orthogonalize = NULL,
  workers = NULL
)

fft_dst(
  x,
  type = 2L,
  inverse = FALSE,
```

```
  n = NULL,
  axes = NULL,
  norm = c("backward", "ortho", "forward", "none"),
  orthogonalize = NULL,
  workers = NULL
)
```

Arguments

`x`	A double, integer, logical or complex vector or array. Complex input is transformed as its real and imaginary parts separately.
`type`	The transform type: 1, 2, 3 or 4.
`inverse`	`TRUE` for the inverse transform.
`n`	Transform lengths, one per transformed axis in the order of `axes` (no recycling); with `axes = NULL`, one per dimension, in dimension order. Each axis of `x` is cropped or zero-padded to its length first. `NULL` keeps the lengths of `x`. For `fft_c2r()`, `n` gives the lengths of the real output; the halved axis of `x` must then hold `n %/% 2 + 1` values and is cropped or padded to that. Its default is `2 * (m - 1)` for an input extent `m`, which is always even: give `n` to recover an odd length.
`axes`	The dimensions to transform, 1-based, without repeats. `NULL` means all of them, in order; for `fft_r2c()` and `fft_c2r()` it means all of them in reverse order, so the first dimension is halved. With explicit `axes`, the real transforms halve the last axis listed, as SciPy does: `axes = seq_along(dim(x))` halves the last dimension. Use `axes = 1` for a column-wise transform of a matrix, as `stats::mvfft()` does.
`norm`	Where the scaling goes, as in `fft_c2c()`. `"ortho"` makes the transform orthonormal when `orthogonalize` is `TRUE`.
`orthogonalize`	Whether to scale the first and last terms so that the `"ortho"` transform matrix is orthogonal. `NULL` (the default) means `norm == "ortho"`, as in SciPy. For complex input an explicit value is ignored and `norm == "ortho"` is used, as SciPy does.
`workers`	Threads to use. `NULL` uses the session default (1). Negative values count back from the number of available cores: `-1` means all of them. Requests are capped at the available cores, and at 2 when `_R_CHECK_LIMIT_CORES_` is set. Threads split the independent 1-D transforms of a multi-dimensional array, so they help only arrays with at least 32 768 elements and more than one line. Results agree to rounding whatever the number of threads; they are bit-identical on builds without fused multiply-add (CRAN's x86-64 builds).

Details

Unnormalised (`norm = "backward"` or `"none"` in the forward direction), for a length `N`, `fft_dct()` computes

- type 1: `y[k] = x[0] + (-1)^k x[N-1] + 2 sum_{n=1}^{N-2} x[n] cos(pi k n / (N-1))`
- type 2: `y[k] = 2 sum_{n=0}^{N-1} x[n] cos(pi k (2n+1) / (2N))`
- type 3: `y[k] = x[0] + 2 sum_{n=1}^{N-1} x[n] cos(pi (2k+1) n / (2N))`

- type 4: `y[k] = 2 sum_{n=0}^{N-1} x[n] cos(pi (2k+1) (2n+1) / (4N))`

and `fft_dst()` the matching sine sums (type 1 over `N + 1`, types 2 to 4 as above with sines and indices shifted by one). Type 1 needs lengths of at least 2 for the cosine transform.

`inverse = TRUE` computes the inverse: types 2 and 3 swap, and the scaling moves to the other direction. With `norm = "backward"` the inverse is scaled by `1/N`, where `N` is `2(n - 1)` for DCT-I, `2(n + 1)` for DST-I and `2n` otherwise, per transformed axis, so that `fft_dct(fft_dct(x), inverse = TRUE)` returns `x`.

Value

A double vector or array (complex for complex input) of the same shape as `x` after cropping or padding to `n`.

See Also

Other transforms: `fft_c2c()`

Examples

```
x <- c(1, 2, 3, 4, 3, 2)
fft_dct(x)
fft_dct(fft_dct(x), inverse = TRUE)
fft_dst(x, type = 4, norm = "ortho")

# an orthonormal DCT-II along the columns of a matrix
m <- matrix(rnorm(12), 4, 3)
fft_dct(m, axes = 1, norm = "ortho")
```

`fft_freq` *Sample frequencies*

Description

`fft_freq()` returns the frequency of each entry of a length-`n` transform from `fft_c2c()`, in cycles per unit of the sample spacing `d`: `0, 1, ..., ceiling(n / 2) - 1, -floor(n / 2), ..., -1`, divided by `d * n`. `fft_rfreq()` returns the frequencies of the `n %/% 2 + 1` entries of `fft_r2c()`: `0, 1, ..., n %/% 2`, divided by `d * n`. They are SciPy's `fftfreq()` and `rfftfreq()`.

Usage

```
fft_freq(n, d = 1)

fft_rfreq(n, d = 1)
```

Arguments

`n`	The transform length, a positive whole number.
`d`	The sample spacing, a positive number.

Value

A double vector.

See Also

Other helpers: `fft_next_len()`, `fft_shift()`

Examples

```
fft_freq(8)
fft_freq(7, d = 0.1)
fft_rfreq(8)
```

`fft_next_len` *Fast transform lengths*

Description

`fft_next_len()` returns the smallest length at least `n` that zufft transforms fastest, and `fft_prev_len()` the largest at most `n`. Padding or cropping an input to such a length with the `n` argument of the transforms can speed them up considerably. They are SciPy's `next_fast_len()` and `prev_fast_len()`.

Usage

```
fft_next_len(n, real = FALSE)

fft_prev_len(n, real = FALSE)
```

Arguments

`n`	Positive whole numbers, at most 2^52.
`real`	`TRUE` for the lengths of real transforms (`fft_r2c()`, `fft_c2r()`, `fft_dct()`, `fft_dst()`).

Details

Fast lengths have no prime factor above 11 for complex transforms, or above 5 for real ones (`real = TRUE`), as in ducc0's `good_size`.

Value

A double vector of the same length as `n`.

See Also

`stats::nextn()`, R's own version for `stats::fft()`.

Other helpers: `fft_freq()`, `fft_shift()`

Examples

```
fft_next_len(c(1009, 999983))
fft_next_len(1009, real = TRUE)
fft_prev_len(1009)
```

`fft_shift` *Shift the zero frequency to the centre*

Description

`fft_shift()` rotates each chosen dimension of `x` by `floor(n / 2)`, so that the zero-frequency entry of a transform sits in the middle; `fft_ishift()` undoes it. They are SciPy's `fftshift()` and `ifftshift()`. `dim`, `dimnames` and `names` move with the values.

Usage

```
fft_shift(x, axes = NULL)

fft_ishift(x, axes = NULL)
```

Arguments

`x`	A vector or array.
`axes`	The dimensions to shift, 1-based. `NULL` means all of them.

Value

`x`, rotated.

See Also

Other helpers: `fft_freq()`, `fft_next_len()`

Examples

```
fft_shift(fft_freq(8))
fft_ishift(fft_shift(1:7))
```

`fft_stats` *Drop-in replacements for stats::fft() and stats::mvfft()*

Description

`fft_stats()` and `mvfft_stats()` take the same arguments, check them the same way and return the same structure as `stats::fft()` and `stats::mvfft()`: the attributes of `z` are kept, the inverse is not scaled, and inputs of length 0 or 1 come back unchanged (as complex). The values agree to rounding. The differences: every length runs in O(n log n) (R's code is quadratic in a large prime factor), real input uses a real transform, and threads follow `fft_workers()`.

Usage

```
fft_stats(z, inverse = FALSE)

mvfft_stats(z, inverse = FALSE)
```

Arguments

`z`	A real or complex vector or array (`fft_stats()`), or matrix (`mvfft_stats()`).
`inverse`	`TRUE` for the unnormalised inverse transform. `NA` means forward, as in `stats::fft()`.

Details

A package moves by replacing `fft(` with `zufft::fft_stats(` and adding zufft to `Imports`.

Value

A complex vector, array or matrix with the attributes of `z`.

Examples

```
x <- 1:4
fft_stats(x)
fft_stats(fft_stats(x), inverse = TRUE) / length(x)
all.equal(fft_stats(x), stats::fft(x))

m <- matrix(rnorm(12), 4)
all.equal(mvfft_stats(m), stats::mvfft(m))
```

fft_workers — *Threads per transform*

Description

`fft_workers()` gets or sets the number of threads a transform uses when its `workers` argument is `NULL`. `with_fft_workers()` sets it while `code` runs and `local_fft_workers()` until the calling function returns, in the style of the withr package; both restore the old value. Together they are SciPy's `get_workers()` and `set_workers()`.

Usage

```
fft_workers(n = NULL)

with_fft_workers(n, code)

local_fft_workers(n, .local_envir = parent.frame())
```

Arguments

`n`	A non-zero whole number. `NULL` (in `fft_workers()`) only reads the current value.
`code`	Code to run with `n` threads.
`.local_envir`	The environment whose exit restores the old value.

Details

A positive value asks for that many threads; a negative one counts back from the number of available cores, so `-1` means all of them. Requests are capped at the available cores, and at 2 when `_R_CHECK_LIMIT_CORES_` is set (as during `R CMD check`). The initial value is 1, as in SciPy.

Threads help when a transform has many independent lines (the columns of a matrix, a multidimensional array) and at least 32 768 elements; a single 1-D real transform always runs on one thread. Results agree to rounding whatever the number of threads, and are bit-identical on builds without fused multiply-add, such as CRAN's x86-64 binaries.

Value

`fft_workers()` returns the current value when `n` is `NULL`, and otherwise the previous value, invisibly. `with_fft_workers()` returns the value of `code`; `local_fft_workers()` returns the previous value, invisibly.

Examples

```
fft_workers()
with_fft_workers(2, fft_c2c(matrix(rnorm(1e4), 100), axes = 1))
f <- function() {
  local_fft_workers(2)
```

```
  fft_workers()
}
f()
fft_workers()
```

`zufft_info` *Information about the zufft build*

Description

Reports which ducc0 source zufft was built from and how: the vendored commit and the SciPy commit that pins it, the SIMD backend and vector width the compiler selected, whether the target has fused multiply-add instructions, the threading mode, and the thread pool.

Usage

```
zufft_info()
```

Value

A named list:

`ducc0_commit` ducc0 commit of the vendored FFT subset.

`scipy_commit` SciPy commit whose vendoring script pins it.

`simd_backend` `"ducc0"`, `"std::experimental::simd"` or `"none"`.

`simd_width` Doubles per SIMD vector, `1` without SIMD.

`fma` `TRUE` if the target has fused multiply-add.

`fp_contract` `"off"` when the transforms never fuse multiply-adds, so results are bit-identical whatever `workers` is; `"fast"` for a GCC build targeting FMA hardware, where they can differ in the last bit. CRAN's builds are `"off"`.

`threading` `"zufft"` when zufft supplies the thread pool, `"none"` when threads are compiled out.

`pool_size` Threads the pool can use now, the caller included.

`hardware_threads` Threads the hardware offers.

`complex_path` `"zero-copy"` when complex vectors are viewed in place, `"marshal"` when they are copied (design §12.2).

Examples

```
zufft_info()$simd_width
```

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