Using Julia Well

perspectives, practices, pragmatics

Jeffrey A Sarnoff

Julia Innovator

Julia Users Group NYC meetup

Thursday, 2022-Aug-28

Being around people here deeply deeply accelerates the learning process. A lot of really cool folks here did the same for me ... and I am eternally grateful for their guidance. Glad you got to do the same ☺ .

– otde on Zulip

Learn from us

The Julia Community is welcoming, helpful, and self-respecting.

Your question is a good one. Ask. We will not think less of you.

- The people who are experts now **all** asked questions.

do see if the answer is readily available (docs, Discourse, Zulip, SO)

ask about technique, ask to clarify, ask for explanation

- where to ask: Discourse, Zulip, Slack
- how to ask: discourse.julialang.org/t/please-read-make-it-easier-to-help-you/14757
- what to ask: explain what it is that you want to know, what you seek to have happen

with Julia

To consider Julia merely a programming language is to lose advantage.

Enhance your own effectiveness

look for ways that simplify, clarify, and engage … use them often.

Elevate aspects of your professional style

Read your own work, even when it works correctly – especially then.

Explain with words and design. Persuade with code. Convince with tests.

with Julia

To consider Julia merely a programming language is to lose advantage.

Enhance your own effectiveness

look for ways that simplify, clarify, and engage … use them often.

keep it simple. get it working. note what you want it to be doing.

clear away the overdone. revisit, reflow. only then address speed.

Elevate aspects of your professional style

Read your own work, even when it works correctly – especially then.

Explain with words and design. Persuade with code. Convince with tests.

Tuples

Tuples are one of the core datatypes in Julia.

- They should be relatively small

  ≤ 32 items is optimized in all sorts of ways

  ≤ 64 items is optimized in important ways

- They are most performant when of uniform concrete type
  if that is a bitstype, so much the better

- They are still worthwhile when of different concrete types
  if there are ≤ 3 different concrete types, good things happen
  (really its ≤ 4 different concrete types, but think of it as 3)

- Tuples look like this

```
()  (1,)  (1, 2)  ("abc", pi)
```

Named Tuples

- All the fun of Tuples, now with names enfolded.
- More trustworthy: `routing.destination is more helpful than routing[2]`
- More easily shared, maintained, **explained**

Named Tuples

- All the fun of Tuples, now with names enfolded.
- More trustworthy: `routing.destination is more helpful than routing[2]`
- More easily shared, maintained, **explained**

```
> emily_rey = (firstname = "Emily", lastname = "Rey", badge = 12)
(firstname = "Emily", lastname = "Rey", badge = 12)

> emily.firstname, emily[:firstname], emily[1]
("Emily", "Emily", "Emily")
```

What about people who are not Emily?

NamedTuples *at a party with the cool kids*

```
newhire( firstname, lastname, badge ) =
     ( ; firstname, lastname, badge )
```

```
emily_rey = newhire( "Emily", "Rey", 12 )
       (firstname = "Emily",
                  lastname = "Rey",
                             badge = 12 )
```

Named Tuples

```
emily_rey == (firstname = "Emily", lastname = "Rey", badge = 12)

struct NewHire{AkoString}
  firstname::AkoString
  lastname::AkoString
  badge::Int

end

NewHire(nt::NamedTuple) = NewHire( nt... )
EmilyRey = NewHire(emily_rey)
EmilyRey.badge == emily_rey.badge
```

Named Tuples

```
> well_paid_employee = newhire( "Emily", "Rey", 12 )
( firstname = "Emily", lastname = "Rey", badge = 12 )
> firstname, lastname, badge = well_paid_employee
( "Emily", "Rey", 12 )

> keys( well_paid_employee )

( :firstname, :lastname, :badge )
> values( well_paid_employee )
( "Emily", "Rey", 12 )
```

Named TupleTools

```
> using NamedTupleTools

> select(employee, (:firstname, :lastname))
(firstname = "Emily", lastname = "Rey")

> delete(employee, :badge)

(firstname = "Emily", lastname = "Rey")

> id, name = split(employee, :badge)

((badge = 12,), (firstname = "Emily", lastname = "Rey"))

> merge(id, name)                                       # create new

(badge = 12, firstname = "Emily", lastname = "Rey")
```

write clean code

not there yet, rewrite it (developing good habits)
not sure what to do, look at other solutions or ask

iteration

```
  for current_value   in            xs  .. end    # avoid index nums
  for current_index   in eachindex(xs) .. end    # these are fast
  for (index, value) in enumerate(xs) .. end    # and future proof
  for current_column in eachcol(amat) .. end    # prefer bycol 2x+
```

lazy comprehension

```
 ys = (x^2 for x in xs) # Base.Generator{Vector{Int64}, ..
 zs = zip(xs, ys)       # zip is lazy and surprisingly fast
```

Integers

overflow and underflow happen when Int types wrap

```
> typemin(Int8), typemax(Int8)
(-128,  127)

> typemin(Int8) - one(Int8), typemax(Int8) + one(Int8)
( 127, -128)
```

What to do?

look out for logic that may wrap, widen your type

test the domain – sample everywhere, corners, combinations

What about mission critical code, math & physics research, money?

betting the farm? use Safer Integers.

SaferIntegers

```
> using SaferIntegers

> zero = SafeInt16(0)

> a = 32_000 + zero;

> a + 999

ERROR: OverflowError: 32000 + 999 overflowed for type Int16
> typemin(SafeInt16) - 1  # underflow is an OverflowError
ERROR: OverflowError: -32768 - 1 overflowed for type Int16
```

using floats

Please do. Just do not take the trailing digits of your results too seriously.

However, if you want reliable trailing digits .. there are helpful packaged types.

- Quadmath.jl exports Float128

  (calculate using Float128, convert the result to Float64)
- DecFP.jl exports Dec128, Dec64

  (calculate using Dec128, convert the result to Float64)
- DoubleFloatsjl exports Double64

  (calculate using Double64, that is all you need to do)

comparing floats

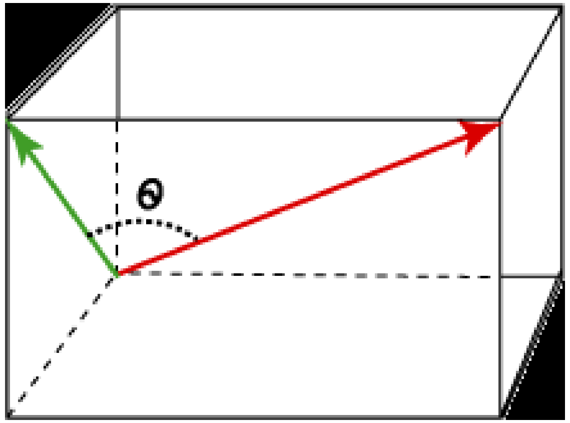
never compare floats for equality

- almost never (testing derived values exactly match rounded constants)
    - and then use `===` so others will know what you intend
- use `isapprox` (`≈` for isapprox with defaults) rather than `==`
    - `atol` sets the absolute difference required to match
    - `rtol` sets the proportional difference (# of sigbits) required to match
    - it is ok to use both, with `atol` set for values near 0.0

isapprox

```
tolerance(T::Type, proportion=0.618034) =      # books use = 1/2
  map(T, tolerance(relbits(T, proportion)))

tolerance(nbits; abstol_power = 2.125) =

  ( rtol = 2.0^(-nbits), atol = 2.0^(- nbits * abstol_power) )

relbits(T::Type, proportion) =

  floor(Int, proportion * Base.significand_bits(T))

const RTOL = ldexp(2.0, -33)     # 2.328e-10 ~ 2.0^(-33)
const ATOL = ldexp(2.0, -70)     # 3.388e-21 ~ 2.0^(-70)

≃(x, y) = isapprox(x, y; rtol=RTOL, atol=ATOL)    # if a ≃ b ..
```

AngleBetweenVectors



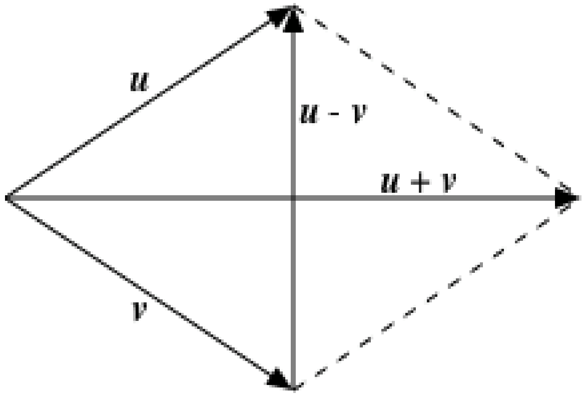
Start with Math. Finish with Numerics.

The dot product of two normalized vectors equals the cosine of their separating angle.

unstable and inaccurate at very small angles

Start with Math. Finish with Numerics.

The sum and difference of two equilength vectors are orthogonal. We use this to find the angle in a stable and robust manner.



AngleBetweenVectors

```
using AngleBetweenVectors   # with Tuples, NamedTuples, Vectors

smaller_angle = angle(point1, point2)

                            # to add a new point representation
struct Point2D{T}           # provide a point constructor
  x::T
  y::T
end                         # define a Tuple(::point) method

Base.Tuple(p::Point2D{T}) where T = (p.x, p.y)
```

AngleBetweenVectors

```
@inline norm2(p::P) where {P<:NTuple{N,T}} where {N,T} =
  sqrt(foldl(+, abs2.(p)))

@inline normalize(p ::P) where {P<:NTuple{N,T}} where {N,T} =
  p ./ norm2(p)

# works with any point type that has Tuple(point) defined
Base.angle(pt1::T, pt2::T) where T =
  angle(Tuple(pt1), Tuple(pt2))
```

AngleBetweenVectors

```
function Base.angle(pt1::P, pt2::P) where {N,T, P<:NTuple{N,T}}
  unitpt1 = normalize(pt1)                    # map pts to unit length
  unitpt2 = normalize(pt2)


  y = norm2(unitpt1 .- unitpt2)

  x = norm2(unitpt1 .+ unitpt2)
end                # result remains robustly consistent + stable
 2 * atan(y, x)    # if lsb[s] are off for the precision given
function Base.angle(pt1::P, pt2::P).. # protecting against the almost certainly never
  # …                                 # is the math expressing never impeccable (no)
  a = 2 * atan(y, x)                  # be runtime savvy to do this, and do this
  isallgood(a) ? a : clip(a)          # isallgood(a) = 0 <= a <= T(pi)

end                                   # clip(a) = a < 0 ? zero(T) : T(pi)
```

abstractions, concrete unions

```
> x = [59, "two"]; typeof(x) == Vector{Any}
> c = concrete(x); typeof(x) == Vector{Union{Int64, String}}
```

```
function concrete(x::AbstractArray)
  ConcreteTypes = Union{typeof.(x)...}
  length(Base.uniontypes(ConcreteTypes)) > 3 && return x


  BaseType = eval(typeof(x).name.name)
  ndim = length(size(x))
  BaseType{ConcreteTypes, ndim}(x)
end
```

abstractions, concrete unions

```
> x = [59, "two"]; typeof(x) == Vector{Any}
> c = concrete(x); typeof(x) == Vector{Union{Int64, String}}

function concrete(x::AbstractArray)
  ConcreteTypes = Union{typeof.(x)...}
  length(Base.uniontypes(ConcreteTypes)) > 3 && return x


  BaseType = eval(typeof(x).name.name)
  ndim = length(size(x))
  BaseType{ConcreteTypes, ndim}(x)
end
```

Abstract Types

```
abstract type SpaceTime end                    # conceptual whole

abstract type AbstractSpace  <: SpaceTime  end # enfolded constituent
abstract type AbstractTime   <: SpaceTime  end # enfolded constituent
abstract type ReferenceFrame <: SpaceTime  end # specialization


abstract type Clock{Frame<:ReferenceFrame} end # constraint
```

Abstract Types

```
abstract type SpaceTime end                    # conceptual whole

abstract type AbstractSpace  <: SpaceTime  end # enfolded constituent
abstract type AbstractTime   <: SpaceTime  end # enfolded constituent
abstract type ReferenceFrame <: SpaceTime  end # specialization

abstract type Clock{Frame<:ReferenceFrame} end # constraint

# singleton types

struct FrameIsUTC   <: ReferenceFrame end      # ako GMT, Mean Time
struct FrameIsLocal <: ReferenceFrame end      # ako wallclock time
```

Abstract Types

```
abstract type Period <: AbstractTime end

struct Hour   <: Period value::Int64 end
struct Minute <: Period value::Int64 end
```

Abstract Types

```
abstract type Period <: AbstractTime end

struct Hour   <: Period value::Int64 end
struct Minute <: Period value::Int64 end

                                          # a good way to use `eval`
for T in (:Year, :Month, :Day, :Hour, :Minute, :Second)
  @eval begin
    struct $T <: Period
      value::Int64
    end
  end

end
```

Abstract Types

```
struct HourMin{Frame} <: Clock{Frame}
  hour::Hour
  minute::Minute
end

HourMin(frame::ReferenceFrame, hr::Hour, mn::Minute) =
    HourMin{frame}(hour, min, sec)

HourMin(frame::ReferenceFrame, hr::T, mn::T) where {T<:Integer}  =
  HourMin(frame, Hour(hr), Minute(mn))

HourMin(hr::Hour, mi::Minute) =  HourMin{FrameIsUTC}(hr, mi)

HourMin(hr::T, mn::T) where {T<:Integer} = HourMin(Hour(hr), Minute(mn))
```

Parametrics

```
struct AnyValue{T}
  value::T
end
intval = AnyValue(8)                # AnyValue{Int64}(8)
strval = AnyValue("abc")            # AnyValue{String}("abc")
```

```
doubleneg(x::FP{+1,T}) where {T} = x
```

Parametrics

```
struct AnyValue{T}
  value::T
end

intval = AnyValue(8)                 # AnyValue{Int64}(8)
strval = AnyValue("abc")             # AnyValue{String}("abc")

struct AnyNumber{T<:Number}
  value::T
end
intval = AnyNumber(8.0)              # AnyNumber{Float64}(8.0)
AnyNumber("abc")                     # MethodError



doubleneg(x::FP{+1,T}) where {T} = x
```

Parametrics

```
struct FP{SGN,T}
  value::T
end

FP(x::T) where T = x<0 ? FP{-1,T}(x) : FP{1,T}(x)

doubleneg(x::FP{+1,T}) where {T} = x
doubleneg(x::FP{-1,T})  where {T} = FP{-1,T}(2 * x.val)

two = FP(+2.0); negthree = FP(-3.0); negsix = FP(-6.0)
doubleneg(two) == two && doubleneg(negthree) == negsix

using Test

@inferred doubleneg(negthree) == negsix
```

Parametrics

```
struct FP{SGN,T}
  value::T
end

FP(x::T) where T = x<0 ? FP{-1,T}(x) : FP{1,T}(x)

doubleneg(x::FP{+1,T}) where {T} = x
doubleneg(x::FP{-1,T})  where {T} = FP{-1,T}(2 * x.val)

two = FP(+2.0); negthree = FP(-3.0); negsix = FP(-6.0)
doubleneg(two) == two && doubleneg(negthree) == negsix
```

Parametrics

```
struct FP{SGN,T}
  value::T
end

FP(x::T) where T = x<0 ? FP{-1,T}(x) : FP{1,T}(x)

doubleneg(x::FP{+1,T}) where {T} = x
doubleneg(x::FP{-1,T})  where {T} = FP{-1,T}(2 * x.val)

two = FP(+2.0); negthree = FP(-3.0); negsix = FP(-6.0)
doubleneg(two) == two && doubleneg(negthree) == negsix

using Test: @inferred

@inferred doubleneg(negthree) == negsix
```

Some Packages

- Tables, TableOperations, DataFrames[Meta], TimeSeries
- Statistics, StatsFuns, Distributions, Random
- Interpolations, Dierckx, LsqFit, BlackBoxOptim, Optimization
- SpecialFunctions, Quadmath, DecFP, [Generic]LinearAlgebra
- JuMP, SciML, Symbolics, ModelingToolkit, DrWatson
- Lazy, Chain, TOML, JSON3, JSONTables, CSV
- MLStyle, IterTools, FastBroadcast, InlineStrings, TupleTools

https://julialang.org/community/organizations/
https://juliahub.com/ui/Search

Tooling

- GitHub or GitLab with GitHub desktop [free on all platforms] or GitKraken
- VSCode with Julia extension [free on all platforms]
- Documenter, Revise, TestEnv, Infiltrator
- BenchmarkTools, PkgBenchmarks, PkgTemplates
- @edit, @which, methods

- Branches – try out an approach without committing to it
- Labels – easily locate the last coherent revision
- Commit messages – really annoying, occasionally worth the arrgh (squash)

What is and is not “type piracy”

your type, your rules

- major version convention

built-in types and other developers' exported types are theirs

- do not redefine methods (exported or not)
- use the type and its methods, do not alter or amend their working
  - do you see an omission, an improvement? post an issue or a PR.
  - there should be a length method, we have the count of elements

your own multimethods are not piracy because they are not theirs

- just use names that are **not** in Base and **try hard not to clash** with imports

sketch what you feel

src/runningsum.jl

```
"""

    runningsum(source, winsize)

Provides the windowed running sum over source.
- result has length(source) - winsize + 1 elements
"""
function runningsum(source::AbstractVector{T}, winsize) where {T}
end
```

test/runningsum.jl

```
@test runningsum([1,2,3,4,5,6], 3) == [6,9,12,15]
```

design concept

```
struct Window{V,I,F}                   # allow many different functions
  source::V                            # data to run window over
  span::I                              # width of the window (nelements)
  apply::F                             # function to apply over window
end

mutable struct Running{V,F,T}          # support running over windows
  window::Window{V,F}                  # generalized window specifier
  firstidx::Int                        # where current window starts
  finalidx::Int                        # where current window ends
  lastvalue::T                         # prior (or first) summary value
end
```

design refinement

```
struct Window{V,I,F}
  source::V
  span::I
  apply::F
end

mutable struct Running{V,F,T}
  window::Window{V,F}
  firstidx::Int
  finalidx::Int
end
  lastvalue::T
```

```
struct Window{V}  struct Runner{F1,F2}
  source::V          setup::F1
  span::Int          update::F2
end               end

struct Running{V,F1,F2}
  runner::Runner{F1,F2}  # applicative
  window::Window{V}      # data surface
  current_start::Int     # running start
end
present(idx, value) = (; idx, value)
```

coding

```
function runningsum(source::AbstractArray{T,N}, winsize) where {T,N}
  # provides a view given a concrete Array
  runningsum(view(source,:), winsize)

end

const ArrayView = SubArray{T,N,P,I,L} where {T,N,P,I,L}

function runningsum(source::ArrayView, winsize)

  # works with a view of the source, not the source directly

end
```

coding

```
function runningsum(source::ArrayView, winsize)
  n = length(source) - winsize + 1              # how many results
  result  = Vector{T}(undef, n)                 # fast allocation
  current = sum(view(source, 1:winsize))        # initialize
  result[1] = current                           # set up result

  @inbounds for idx in 1:n-1                    # proper for algorithm
    current += source[winsize+idx] - source[idx]    # update
    result[idx+1] = current                         # remember
  end

  isallgood(result) ? result : clip(result)     #  ↜allisgood↝
end
```

I recommend working for this person

"Your work always delivers $. It is a tomorrow key for me."
"As a professional , you are ready to .. I’ll see to that."

shuffle up

```
# how a data processing center overcharged my client millions

oldsystem = (; flops =  4)
newsystem = (; flops = 16)
performance_change = newsystem.flops - oldsystem.flops         # 12

performance_multiplier = performance_change / oldsystem.flops  # 3.00
performance_adjusted_unit_cost = 1 + performance_multiplier    # 4.00
```

shuffle up and deal

```
# how the overcharges happened

oldsystem = (; flops =  4)
newsystem = (; flops = 16)
performance_change = newsystem.flops - oldsystem.flops        # 12

performance_multiplier = performance_change / oldsystem.flops # 3.00
performance_adjusted_unit_cost = 1 + performance_multiplier   # 4.00

comparative_advantage = performance_change / newsystem.flops  # 0.75
performance_adjusted_unit_cost = 1 + comparative_advantage    # 1.75
```

Big Picture

- Julia takes some familiarity
  - mostly time to unlearn approaches unhelpful with Julia
  - some time (practice time) to gain ease with the helpful ones

- truly provides community help
  - *no more tears* -- just ask, we are inclined to answer
- speeds good work, encourages cooperation

- less tension, much less self-recrimination

The best of Julia is what you do with Julia