# Metaprogramming

CS315B
Lecture 7

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## Projects

- Time to start thinking about projects!
  - A regent program/library of your choosing
- List of suggested projects will be published later this week
- You can also propose your own
- Working in teams is OK
  - But then we will expect a more ambitious project!

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## What is Metaprogramming?

- Programs that generate programs
- Example: C++ template metaprogramming
- But a very old idea
  - Lisp in the 1950's
  - Explored extensively since the 1980's

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## Why Metaprogramming?

- Reason #1: Performance
- Consider a function $F(X,Y)$
  - $X$ changes with every call
  - $Y$ is one of a small set of possible values
  - Or fixed for long periods of time
- Generate versions $F_Y(X)$ for each value of $Y$
  - And optimize each $F_Y(.)$ separately

## Why Metaprogramming?

- Reason #2: Software maintenance
- Maintaining versions $F_Y(X)$ for each value of Y by hand is painful
- Much easier to maintain a program that auto-generates the needed versions

## Why Metaprogramming?

- Reason #3: Autotuning
  - Based on performance measurements, generate a new version of F(X)
  - Here, machine characteristics are a “hidden”, constant parameter
- May need to generate many versions F(X)
  - Which versions and how many are data dependent
  - The space of possible versions could be very large or even infinite

## Templates using Metaprogramming

- Templates are an instance of metaprogramming
  - Each template argument produces a distinct set of methods, customized to a particular type
- Lua can be used to generate Terra structs and methods
  - Example 32

## Why Does this Work?

- Lua and Terra (and Regent) share a lexical environment
  - Lua variables can be referred to in Terra & Regent
- Terra types are Lua values
  - E.g., Array(float)
- In this example, can only have one ArrayType
  - The name can’t be redefined
  - Can also generate new names (not shown)

## Escape

- Lua can also be used to compute Terra *code*
  - Expressions or statements
- The *escape* operator [ e ] inserts the value of the Lua expression e into a Terra context
  - e is Lua code
  - That evaluates to a Terra expression
- Example 33 & 34

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## Warning! Warning!

- Metaprogramming is tricky
- It is easy to
  - Not get the code you expect
  - Perform illegal operations
    - E.g., adding two pieces of code, instead of two numbers
- Separate
  - Function definition time
  - Function call time
- Metaprogramming takes place at definition time

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## Guideline 1

- An escape operation […] should contain
  - A call to a Lua function
  - An explicit quote `…
  - Not strictly necessary, but these are the common cases

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## Guideline 2

- To do metaprogramming, you will need both values and code at function-definition time
  - The values may appear in the final code
  - Or be used for computing the code
- Values that you use in metaprogramming
  - Must be defined at the Lua level
  - Outside of any Terra functions or Regent tasks
  - Examples 35-38

## Metaprogramming in Regent

- Regent metaprogramming is similar to Terra
- Escape is still [ … ]
- Quote is rexpr … end
- Example 39
  - New feature: A Lua function that returns a Regent task

## Stencil.rg

- A sophisticated example of Regent metaprogramming

## Semantics

- It is worth understanding in some detail the semantics of metaprogramming in Lua/Terra/Regent.
- There are a number of steps …

## Semantics

- Step 1: Lua code evaluates normally until it reaches
  - a Terra/Regent function definition
  - A quote expression

## Semantics

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- Step 2: A Terra/Regent expression is specialized in the local environment, by evaluating all escaped Lua expressions

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- Step 1: Lua code evaluates normally until it reaches a Terra/Regent definition or a quote
- Step 2: A (Terra/Regent) quote is simply returned as code
  - Internally, a code data type

## Semantics

- Step 1: Lua code evaluates normally until it reaches a Terra/Regent definition or a quote
- Step 2: The Terra/Regent expression is specialized in the local environment, by evaluating all escaped Lua expressions
- Step 3: When a Terra/Regent function is called, it is JIT compiled and returns a Terra/Regent code value.

## Back To Step 2

- Step 2: The Terra/Regent expression is specialized in the local environment, by evaluating all escaped Lua expressions
- In this step, Lua/Terra/Regent share the same lexical environment
  - Escaped Lua expressions are evaluated
  - Lua variable references are replaced by their values
    - Must be coercable to a Terra/Regent value!

## Back To Step 3

- Step 3: When a Terra/Regent function is called, it is JIT compiled and returns a Terra/Regent code value.

- Terra/Regent execute in a separate environment
  - All variable references are to Terra/Regent values
  - Can still call Lua functions, though!
    - Be careful
    - Will call into the local Lua interpreter on the node

## Critique of Metaprogramming

- Most metaprogramming systems are designed to use language X to program in language X
  - Lisp
  - Scheme
  - MetaOCaml

- Plus
  - Expressive languages, easy to manipulate code programmatically

- Minus
  - Limits the performance that can be obtained
  - Because the languages are (usually) untyped, high-level, garbage-collected

## Other Approaches

- Other approaches involve metaprogramming in lower-level languages through a variety of mechanisms
  - Template metaprogramming (C++)
  - Preprocessors (C)
  - Printf and recompile (C)

- Plus
  - Code can be as fast as possible

- Minus
  - Bizarre restrictions, cumbersome to use, not completely general

## Metaprogramming with Lua/Terra/Regent

- Use a high-level language to metaprogram lower-level languages

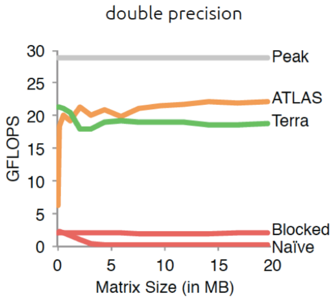
- Plus
  - Generality, expressivity & performance
  - Key is shared lexical scope

- Minus
  - Need to understand two/three languages
  - Need to understand evaluation semantics

## Lua/Terra for ATLAS

- ATLAS provides autotuned matrix multiply routines
  - Combination of X86 asm, C, C-preprocessor, Makefiles, custom scripts
- Terra version
  - *Staged* (metaprogrammed) Terra code
  - Autotuning written in Lua
    - Selecting optimal subproblem sizes for a machine
  - Optimizations: vectorization vector(float,4), register blocking, cache blocking, unrolling
  - Total code is ~250 lines

## ATLAS Results



## Metaprogramming/Autotuning Regent

- Tune size/number of regions
- Tune depth of region tree
  - How many levels of decomposition is best?
- Specialize code to individual subregions
  - E.g., boundary vs. interior
  - E.g., repetitive sparse patterns
- Perform optimizations
  - But note the Regent compiler does some optimizations already

## Summary

- Metaprogramming is a very powerful tool
  - You can program your own compiler functionality
- Not as exploited as it should be
  - And Lua/Terra/Regent makes it easier to use
- Give it a try!