Dao Programming Language for Scripting and Computing

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September 18, 2013

StrangeLoop 2013: Emerging Languages Camp

Outline

Overview: Development Motivation

Initial motivation: Perl!

My frustration with Perl made me very curious about language design and implementation.

Another motivation: Bioinformatics.

I really wanted a better porgramming language for bioinformatics.

Now the goal is to create a general purpose language

that offers advanced features supported by a small runtime, with emphasis on:

- rich but non-redundant data types and features;
- consistent and reasonably designed syntax;
- simple programming interfaces for extending and embedding;
- good efficiency for numeric computation;
- good support for multicore machines;

Overview: Syntax Style and Performance Expectation

What kind of syntax can you expect from Dao?

```
# With implicit types:
routine Sum( nums )
{
    sum = 0
    for (x in nums) sum += x
    return sum
}
ints = {1 : 2 : 1000}
fut  = Sum( ints ) !!
sum  = fut.value()
```

```
# With explicit types:
routine Sum( nums : list<int> ) => int
{
    sum : int = 0
    for (x in nums) sum += x
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ints : list<int> = {1 : 2 : 1000}
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What kind of performance can you expect from Dao? *(Time in seconds)*

Program	Argument	Dao	Dao+JIT	Speedup	Lua	Python	C (-O2)
fannkuch	11	59.3	16.0	3.7X	135.1	279.0	2.9
mandelbrot	4000	24.1	4.3	5.7X	55.8	132.1	2.3
nbody	10000000	35.7	11.9	3.0X	93.2	261.4	1.7
spectral-norm	5000	20.5	2.0	10.4X	69.4	287.1	1.9
binary-trees	16	30.4	30.3	1.0X	20.7	19.7	4.5
meteor	2098	5.5	5.5	1.0X	2.1	9.6	0.1

Overview: Feature Lists

Key Features

- **Optional typing** with **type inference** and static type checking;
- BNF-like **syntax macro** for defining customized syntax;
- Native support for **concurrent programming**;
- LLVM-based **Just-In-Time (JIT) compiling**;
- **Simple C interfaces** for easy embedding and extending;

Other Main Features

Modules and Tools

Overview: Feature Lists

Key Features

Optional typing, syntax macro, concurrent programming, JIT compiling etc.

Other Main Features

- Has **enum symbols**, **tuples**, **numeric arrays** and **hash maps** etc.;
- Object-Oriented Programming (**OOP**) with **classes** and **interfaces**;
- Support **mixin** class, **class decorator** and **aspect class** (for AOP);
- Support **coroutines**, **decorators**, **anonymous functions** and **closures**.
- **Code section methods** as an alternative to functional methods;
- Built-in support for **string pattern matching**;
- Template-like C data type;
- Designed and implemented as a **register-based virtual machine**;
- Bytecode file format, archive file format and single file deployment.

Modules and Tools

Overview: Feature Lists

Key Features

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Other Major Features

Rich data types, OOP, mixins, aspects, coroutines, decorators, anonymous functions, closures, code section methods and string pattern matching etc.

Major Modules and Tools

- Standard online **help** system;
- Standard module for data **serialization**;
- Clang-based module to support **mixing C/C++ code** with Dao code;
- ClangDao: Clang-based tool for **automatic wrapping** of C/C++ libraries;
- DaoStudio: Integrate Developement Environment;

Optional Typing in Dao

Typical places to use optional types:

- **Variable declaration:**

```
tup : tuple<int,string> = ( 123, 'abc' )
tup                     = ( 123, 'abc' )
```

- **Function declaration:**

```
routine Test( a : float = 0.0 ) => int { return a > 1.0 }
routine Test( a         = 0.0 )        { return a > 1.0 }
```

- **Class definition:**

```
class SimpleClass
{
    var  index : int    = 0
    var  name  : string = 'Joe'
}
class SimpleClass
{
    var  index  = 0
    var  name   = 'Joe'
}
```

Optional Typing in Dao

Type System

Optional typing is enabled by a very simple type system, which does (mostly) **instruction-wise** type inference and static type checking.

Additional features enabled by this simple type system

- **Instruction specialization:**
- **Function specialization (at both compiling and running time):**
- **Boilerplate code saving:**

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- **Instruction specialization:**

```
a = 123
b = a + 456
```

  The addition in the above code will be compiled into **ADD**, then specialized to **ADD_III** for integer type operands after type inference.

- **Function specialization (at both compiling and running time):**
- **Boilerplate code saving:**

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- **Instruction specialization:**
- **Function specialization (at both compiling and running time):**

```
routine Test( a ){ return a + a }

Test( 123 )
Test( 'abc' )
```

The `Test(a)` function will be specialized at compiling time into two functions `Test(a:int)` and `Test(a:string)` according to the calling parameters.

- **Boilerplate code saving:**

Optional Typing in Dao

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Additional features enabled by this simple type system

- **Instruction specialization:**
- **Function specialization (at both compiling and running time):**
- **Boilerplate code saving:**
  To wrap C function `int test(float a)` for Lua or Python, one has to write *boilerplate code to check the parameter types*. But **not in Dao**,

```
void dao_test( DaoProcess *proc, DaoValue *par[], int n )
{
    float a = par[0]->xFloat.value;
    DaoProcess_PutInteger( proc, test( a ) );
}
```

  Parameter type checking is not necessary if the wrapping function is registered with a **proper signature**,

```
DaoNamespace_WrapFunction( ns, dao_test, "test(a:float)=>int" );
```

Dao Syntax Macro

Basic idea:

Syntax of programming languages can often be specified by the (extended) Backus Normal Form (BNF).

- A **BNF expression** can be view as a **pattern** for both **matching** and **generating** token sequences;
- Combining two BNF (like) expressions, one for **matching** and the other for **generating** token sequences, you get a **BNF-like syntax macro**;

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Dao Syntax Macro

In Dao, syntax macro can be expressed in the following way,

```
syntax [ optional_language_id ] {
    source_syntax_pattern
} as {
    target_syntax_pattern
}
```

Dao Syntax Macro

Example

The following tokens are controlling markers,

- **( )** : pattern grouping;
- **! ? * +** : group repeating;
- **[ ]** : optional group, equivalent to **( ) ?**;

and tokens started with **$** are special variables,

- **$ID** : a valid identifier;
- **$EXP** : an expression or subexpression;
- **$BL** : a block of code may contain any type of syntax structures;

```
syntax { # while do end
    |'while' $EXP1 'do' [ $BL1 ] 'end'
} as {   # while(){}
    |'while' '(' $EXP1 ')' '{' [ $BL1 ] '}'
}

a = 1
while a < 10 do
    |io.writeln( a )
    |a += 1
end
```

Dao Code Section/Block Method

Code Section/Block Methods

Code section method is a special type of method that can take a block of code as an implicit parameter when called. The code block is attached to the call by `::{ [param_name] code_block }`.

- Builtin code section methods:

```
ints = { 123, 987, 376, 345 }
ints.iterate( $backward )::{ [item,index]
    io.writeln( item, index )
}
```

- User defined code section methods:

```
routine Test( maxvalues : list<float> )[ float => float ]
{
    for( max in maxvalues ){
        r = yield( max )  # execute the code section;
        io.writef( 'Random value in [0,%g]: %g\ n', max, r )
    }
}
Test( { 100.0, 200, 300 } )::{ [X] rand( X ) }
```

Dao Decorator, Mixin and Aspect

Decorator

Decorators are functions that can modify (decorate) other functions:

```
routine @Decorator( func : routine ) {
    io.writeln( 'Calling function:', std.about(func) );
    return func( __args__, ... ); # ... for parameter expanding;
}
@Decorator
routine Function() { io.writeln( 'Function()' ); }
```

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```

Mixin

Mixins are classes with members injected from component classes without inheritance:

```
class Component {
    var value = 456
    routine Meth2(){ io.writeln( self, value ) }
}
class Mixin ( Component ) {
    var index = 123
    routine Meth(){ io.writeln( self, index, value ) }
    routine Meth2( a : string ){ io.writeln( self, index, value, a ) }
}
```

Dao Decorator, Mixin and Aspect

Class Decorator

Class decorators are classes whose decorator methods will be automatically applied to mixin classes:

```
class @DecoratorClass {
    routine @Prefix( meth :routine<self:@Decorator> ) for Prefix~ {
        io.writeln( 'Decorator::Prefix()' )
        meth( __args__, ... );
    }
}
class MyMixin ( @DecoratorClass ) {
    routine PrefixTest() {
        io.writeln( 'MyMixin::PrefixTest()' )
    }
}
```

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        meth( __args__, ... );
    }
}
class MyMixin ( @DecoratorClass ) {
    routine PrefixTest() {
        io.writeln( 'MyMixin::PrefixTest()' )
    }
}
```

Aspect

Aspects are decorator classes to be applied to other classes automatically:

```
class @AspectForMyClasses for My~ {
    routine @Method( meth : routine ) for Method~ {
        io.writeln( 'In @AspectForMyClasses::@Method():', std.about(meth) )
        return meth( __args__, ... )
    }
}
```

Concurrent Programming in Dao

Dao has multiple features to support concurrent programming

- Asynchronous Function Call;
- Asynchronous Object;
- Tasklet communication channel;
- Built-in multithreading module **mt**;
- Concurrent garbage collector;

Concurrent Programming in Dao: Asynchronous Function Call

Asynchronous Function Call

- Is a call followed by **!!**;
- Executes in a **separated tasklet** (a very lightweight thread);
- Returns a **future value** (for scheduling and/or retrieving results);

Example

```
routine SumOfLogs( n = 10 )
{
    sum = 0.0
    for( i = 1 : n ) sum += log( i )
    return sum
}

fut = SumOfLogs( 2000000 ) !!    # Asynchronous mode;

while( fut.wait( 0.01 ) == 0 ) io.writeln( 'still computing' )
io.writeln( 'sum_of_logs =', fut.value() )
```

Concurrent Programming in Dao: Asynchronous Object

Asynchronous Object

- An asynchronous object is a class instance created in asynchronous call mode;
- All its methods will be invoked asynchronously (execute in tasklets and return future values);
- Such tasklets are scheduled such that at most one thread task is active for the same instance at any time.

Example

```
class Clustering
{
    routine Run(){ DoKmeansClustering() }
}
cls = Clustering() !!     # Asynchronous mode;
job = cls.Run()
while( 1 ){
    DoSomethingElse();
    if( job.wait( 0.1 ) ) break; # wait for 0.1 second
}
```

Concurrent Programming in Dao: Channel

Tasklet Communication Channel

- Channel allows passing data and synchronizing between tasklets;
- The channel type is implemented as a customized C data type that supports template-like type arguments:

```
chan = mt::channel<int>( 5 )  # integer channel with capacity 5;
```

- It provides two key methods among others:

```
send( self :channel<@V>, data :@V, timeout :float = -1 ) => int

receive( self :channel<@V>, timeout :float = -1 )
  => tuple<data :@V|none, status :enum<received,timeout,finished>>
```

Concurrent Programming in Dao: Channel

Example

```
class Producer
{
    routine Run( chan : mt::channel<int> ){
        index = 0;
        while( ++index <= 100 ) chan.send( index )
        chan.cap(0)  # set channel buffer size to zero to close the channel;
    }
}
class Consumer
{
    routine Run( chan : mt::channel<int> ){
        while(1){
            data = chan.receive()
            io.writeln( "received", data );
            if( data.status == $finished ) break
        }
    }
}
chan = mt::channel<int>(2)
producer = Producer() !!
consumer = Consumer() !!
producer.Run( chan )
consumer.Run( chan )
```

Concurrent Programming in Dao: Multithreading Module mt

Concurrent Programming with mt Module

mt is a built-in module to provide additional multi-threading functionalities. It can be used to create tasklets, but more importantly, it offers **parallelized code section methods** to make certain parallelization much simpler.

Tasklet and future value

Tasklet can be created with **mt.start()::{}**, and handled with a **future value** type.

```
# Start a thread task and return a future value:
fut = mt.start( $now )::{
    sum2 = 0
    for( i = 1 : 1000 ) sum2 += i * i
    return sum2
}
while( fut.wait( 0.01 ) == 0 ) io.writeln( 'still computing' )
io.write( 'sum_of_squares = ', fut.value() )
```

Concurrent Programming in Dao: Multithreading Module mt

Parallelized code section methods

- **mt.iterate()**: iterate on array, list, map, or just a number of iteration;
- **mt.map()**: map items of array, list or map to produce new array or list;
- **mt.apply()**: apply new values to the items of array, list or map;
- **mt.find()**: find the first item that satisfy a condition;

Example,

```
ls = {1,2,3,4,5,6}

# Concurrent iteration:
mt.iterate( times => 10, threads => 4 )::{ io.writeln( X ) }
mt.iterate( ls, threads => 4 )::{ io.writeln( X ) }

# Parallelized mapping and value application:
ls2 = mt.map( ls, 4 )::{ X*X }  # ls2 = {1,4,9,16,25,36}
mt.apply( ls, 4 )::{ X*X }      # ls  = {1,4,9,16,25,36}

# Parallel searching:
num = mt.find( ls, 4 )::{ X > 20 }
```

LLVM-based Just-In-Time (JIT) compiler

- Implemented as a loadable module (DaoJIT);
- Backend based on the **LLVM**;
- Emphasis on **numeric computation**;
- Compiles a subset of Dao virtual machine instructions;

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JIT Performance Test (time in seconds)

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meteor	2098	5.5	5.5	1.0X	2.1	9.6	0.1

Note 1: benchmark programs are taken from *Computer Language Benchmarks Game* `http://shootout.alioth.debian.org`; **Note 2:** the last two are not JIT compiled, because they don't contain enough JIT compilable code (for the current JIT compiler).

ClangDao: bringing C/C++ libraries to your finger tips

- Based on **Clang** (C Language Family Frontend for LLVM);
- Generate bindings directly from C/C++ **header files**;
- Support C/C++ functions, C structs, C callbacks, C++ classes and inheritance, C++ virtual functions, C++ templates (to some extent) etc.;
- Support user-defined wrapping hints expressed as C macros;

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Example input file for ClangDao

- File *mymodule.c*:

```
#define module_name MyModule
#undef module_name
// Hint to mark a pointer parameter as an array of size 3:
#define dao_mytest( p_dao_hint_array_3 ) mytest(int*)
// Constants, functions and classes etc. from the included
// header files will be wrapped:
#include "myheader.h"
```

- Then the bindings can be generated with:

```
$ clangdao -IPathToHeaderFile mymodule.c
```

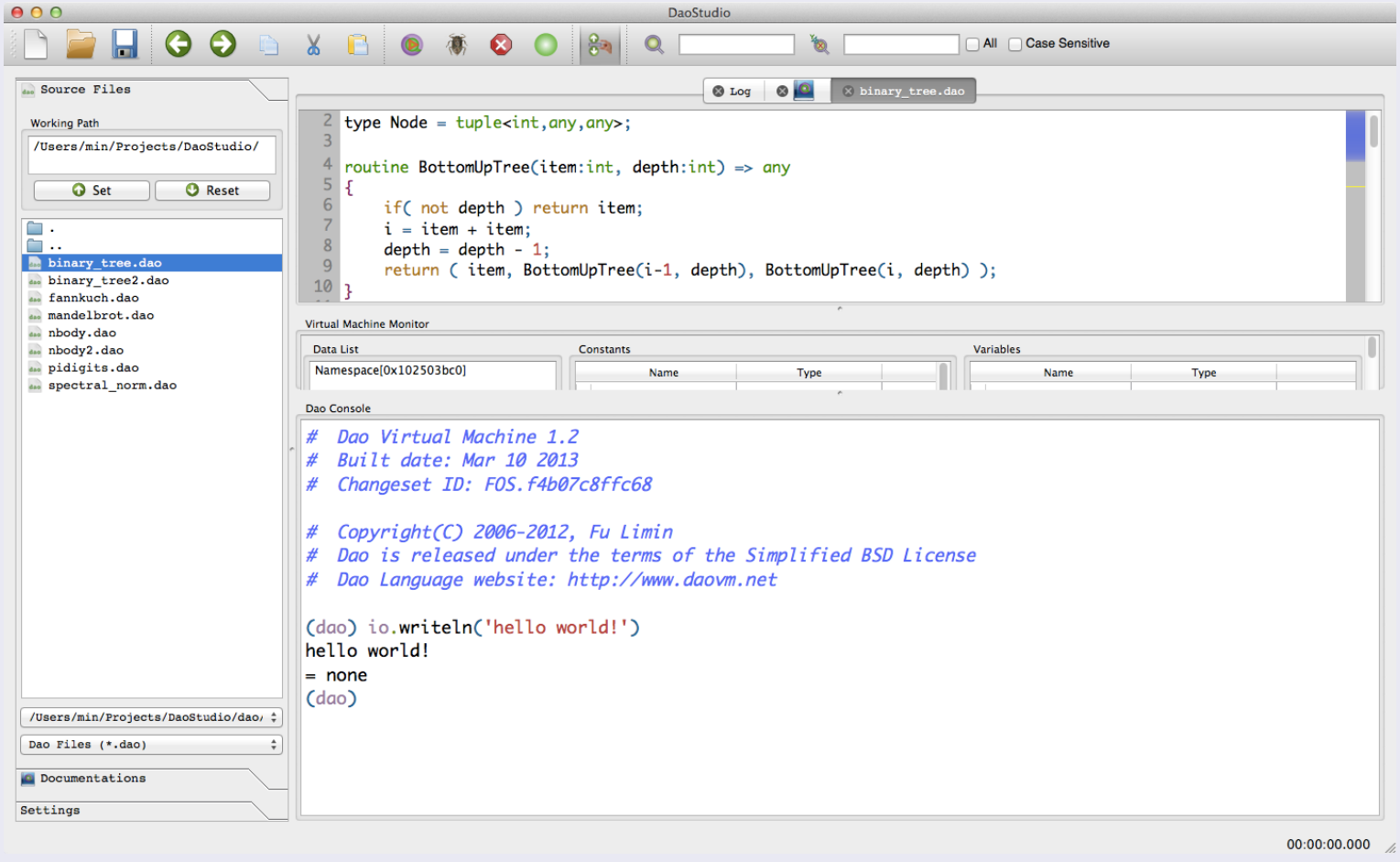
ClangDao: bringing C/C++ libraries to your finger tips

List of bindings generated by ClangDao

Scientific:	Dao**GSL**	GNU Science Library (GSL)
	Dao**BamTools**	BamTools
	Dao**GenomeTools**	GenomeTools
	Dao**SVM**	LibSVM (Support Vector Machine)
Visualization:	Dao**VTK**	Visualization Toolkit
	Dao**MathGL**	MathGL
2D Graphics:	Dao**GraphicsMagick**	GraphicsMagick
3D Graphics:	Dao**OpenGL**	OpenGL
	Dao**Horde3D**	Horde3D Engine
	Dao**Irrlicht**	Irrlicht 3D Engine
Multimedia:	Dao**SDL**	Simple DirectMedia Layer (SDL)
	Dao**SFML**	Simple and Fast Multimedia Library
GUI:	Dao**FLTK**	Fast Light Toolkit (FLTK)
Miscellaneous:	Dao**XML**	libxml2
	Dao**Bullet**	Bullet Physics Engine
	Dao**GameKit**	GameKit Game Engine
	Dao**GamePlay**	GamePlay Game Engine

DaoStudio: Integrate Development Environment for Dao

A cross platform IDE for Dao developed using Qt4



Future Development

Main Development

- Better documentations for the language, modules, and tools;
- Possible improvements to the implementation;
- Development of comprehensive unit tests;
- Further improvements to the JIT compiler;
- Further improvements to the ClangDao tool;
- Further improvements to the DaoStudio IDE;

Acknowledgements

Thanks to *Aleksey Danilov*, *Lucas Beyer*, *Belousov Oleg*, *Zhiguo Zhao* and others for module contributions, testing or bug reports etc.

Thank you for your time!

Homepage: http://daovm.net