

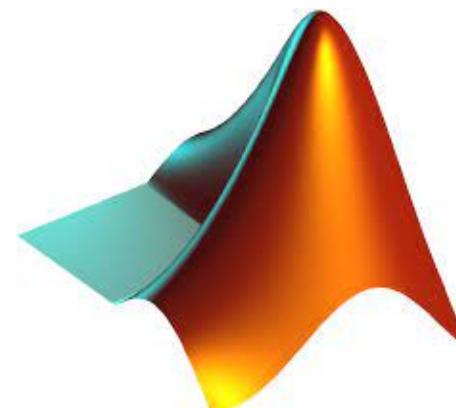


# A fresh approach to Numerical Computing

Zachary Sunberg, Assistant Professor, AERO

# Survey

# Scientific computing is pretty good these days



# Fast Development



# Fast Execution



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# 2011



**Zachary Sunberg**  
@zsunberg

I think [#python](#) might be the programming language I've always wanted.

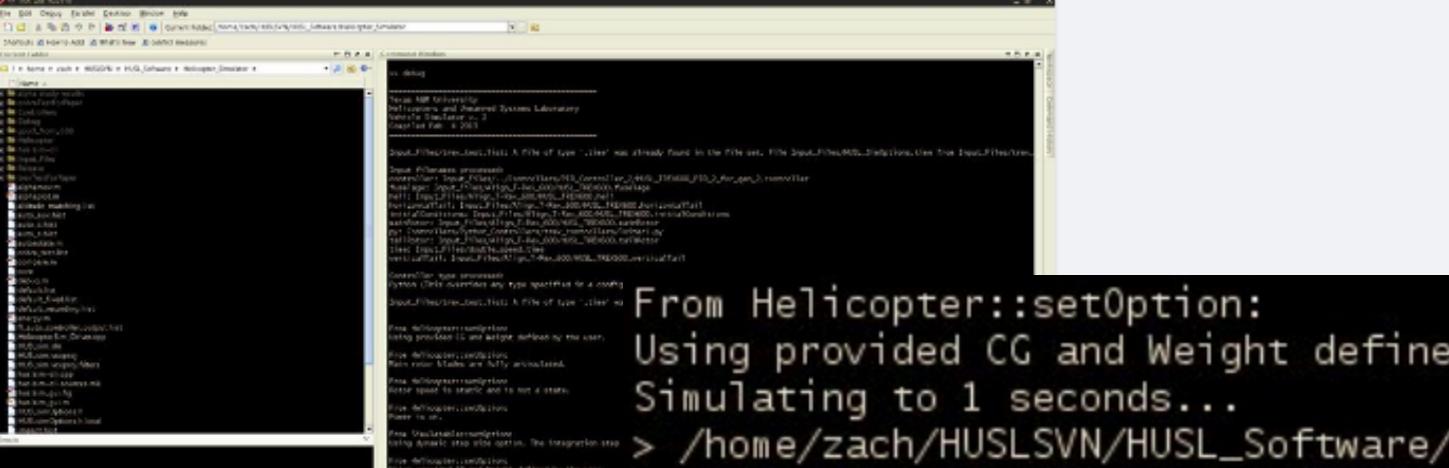
1:25 AM - Feb 3, 2011

[See Zachary Sunberg's other Tweets](#)

# 2013

 **Zach Sunberg**  
February 5, 2013 · 5

Codeception: Interactively debugging a python code that's running inside an application written in C++ that I'm running in the matlab command prompt.



From Helicopter::setOption:  
Using provided CG and Weight defined  
Simulating to 1 seconds...  
> /home/zach/HUSLSVN/HUSL\_Software/H  
-> return bodyToInertial\*uvw  
(Pdb) uvw  
array([ 0.5, 1. , 0. ])  
(Pdb)

 You, Micki Achterhof, David Freese and 5 others like this.  
 Comment  
 Share

 Write a comment...    

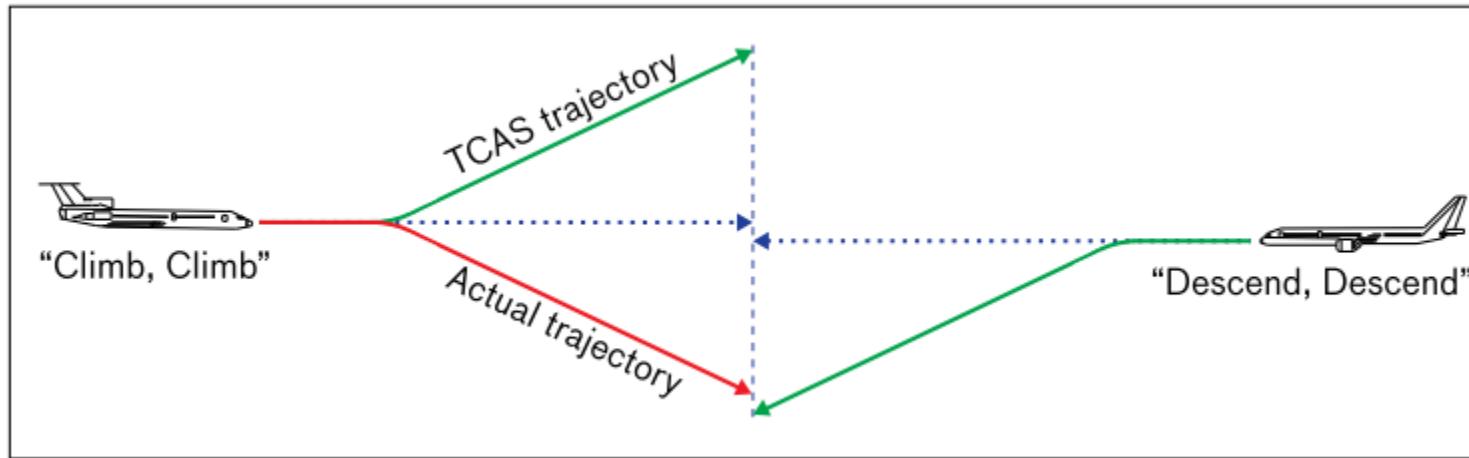
# 2012

We love [Matlab, Lisp, Python, Ruby, Perl, Mathematica, and C]; they are wonderful and powerful. For the work we do — scientific computing, machine learning, data mining, large-scale linear algebra, distributed and parallel computing — each one is perfect for some aspects of the work and terrible for others. **Each one is a trade-off.**

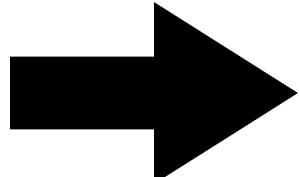
**We are greedy: we want more.**



# Also ~2011: Improving TCAS

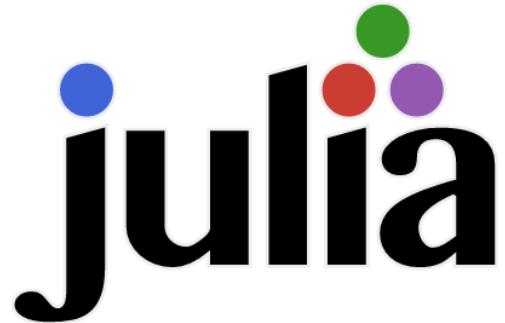


IF (ITF.A LT G.ZTHR)  
THEN IF(ABS  
(ITF.VMD) LT  
G.ZTHR)  
THEN SET ZHIT;  
ELSE CLEAR



**Algorithm 11** ProximityEstimation

```
1 function ProximityEstimation( z_own_ave::R, z_int_ave::R, r_ground_int::R, valid_bearing_int::Bool,  
2                                belief_vert_int::Vector{IntruderVerticalBelief(p. 102)}, quant_int::Z )  
3     D_proximity_range_threshold::R = params().display.proximity_range_threshold  
4     H_proximity_altitude_threshold = params().display.proximity_altitude_threshold  
5     is_proximate::Bool = false  
6     z_rel::R = abs( z_own_ave - z_int_ave )  
7     if (r_ground_int <= D_proximity_range_threshold) && (z_rel < H_proximity_altitude_threshold)  
8         if !IsNARS(p. 95)( belief_vert_int, quant_int ) || valid_bearing_int  
9             is_proximate = true  
10        end  
11    end  
12    return is_proximate::Bool  
13 end
```



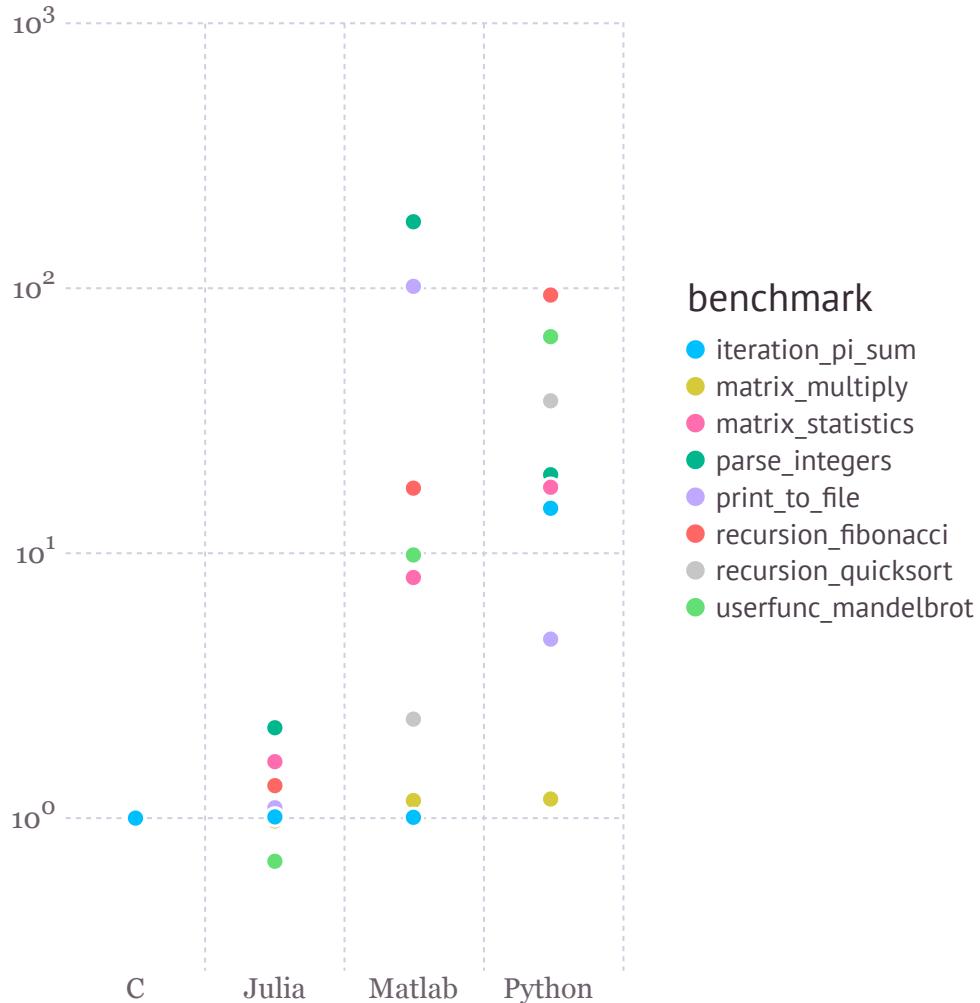
Julia solves the two language problem!

- **EASIER** to read, write, maintain, and collaborate with as Python or MATLAB
- **FASTER** as C

Be skeptical! Find out for yourself!

Others' perspective: <https://web.mit.edu/18.06/www/Spring17/Julia-intro.pdf>

# Julia - Speed

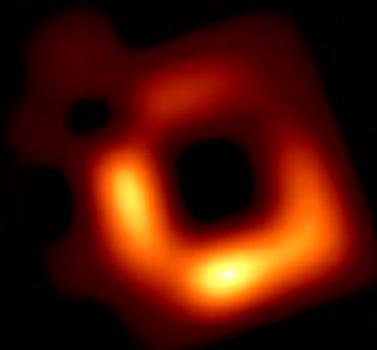


**Celeste Project**  
1.54 Petaflops

# Accelerated Black Hole Imaging with Julia & Enzyme

EHT Tools M87 2017

Image Analysis: ~ **1 week** (cluster)



Julia+Enzyme M87 2017

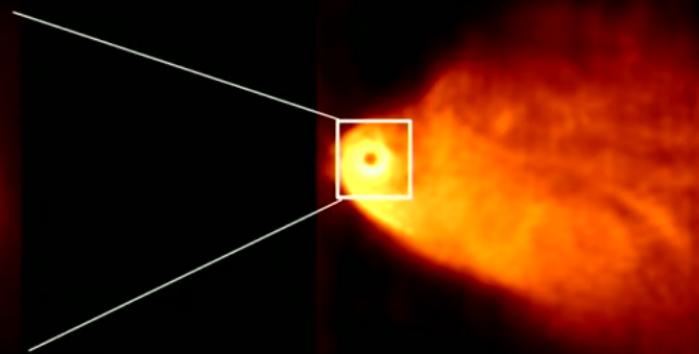
Image Analysis: **1 hour** (1 thread)



Julia+Enzyme next-generation images

Image Analysis: **1-2 days (8 threads)**

(100x increase in computational complexity)



Simulation

Comrade.jl: Julia Bayesian Black Hole Imaging

Paul Tiede, Harvard & Smithsonian | CfA

JuliaCon 2023 (EHT Tools in C++)

Not because Julia is somehow faster, but because it was easier to dev better algs

# Julia

**Algorithm 1** BUILDDESPOT( $b_0$ )

- 1: Sample randomly a set  $\Phi_{b_0}$  of  $K$  scenarios from the current belief.
  - 2: Create a new DESPOT  $\mathcal{D}$  with a single node  $b_0$  as the root.
  - 3: Initialize  $U(b_0), L_0(b_0), \mu(b_0)$ , and  $\ell(b_0)$ .
  - 4:  $\epsilon(b_0) \leftarrow \mu(b_0) - \ell(b_0)$ .
  - 5: **while**  $\epsilon(b_0) > \epsilon_0$  and the total running time is less than  $T_{\max}$  **do**
  - 6:    $b \leftarrow \text{EXPLORE}(\mathcal{D}, b_0)$ .
  - 7:    $\text{BACKUP}(\mathcal{D}, b)$ .
  - 8:    $\epsilon(b_0) \leftarrow \mu(b_0) - \ell(b_0)$ .
  - 9: **return**  $\ell$ .

---

**Algorithm 2** EXPLORE( $\mathcal{D}, b$ )

- ```

1: while  $\Delta(b) \leq D$ ,  $E(b) > 0$ , and  $\text{PRUNE}(\mathcal{D}, b) = \text{FALSE}$  do
2:   if  $b$  is a leaf node in  $\mathcal{D}$  then
3:     Expand  $b$  one level deeper. Insert each new child  $b'$  of  $b$  into  $\mathcal{D}$ . Initialize
    $\mu(b')$ , and  $\ell(b')$ .
4:    $a^* \leftarrow \arg \max_{a \in A} \mu(b, a)$ .
5:    $z^* \leftarrow \arg \max_{z \in Z_{b, a^*}} E(\tau(b, a^*, z))$ .
6:    $b \leftarrow \tau(b, a^*, z^*)$ .
7: if  $\Delta(b) > D$  then
8:   MAKEDEFAULT( $b$ ).
9: return  $b$ .

```

---

**Algorithm 4** PRUNE( $\mathcal{D}, b$ )

- ```

1: BLOCKED  $\leftarrow$  FALSE.
2: for each node  $x$  on the path from  $b$  to the root of  $\mathcal{D}$  do
3:   if  $b'$  is blocked by any ancestor node in  $\mathcal{D}$  then
4:     MAKedefault( $x$ ).
5:     BACKUP( $\mathcal{D}$ ,  $x$ ).
6:     BLOCKED  $\leftarrow$  TRUE.
7:   else
8:     break
9: return BLOCKED.

```

```

27 VNode* DESPOT::Trial(VNode* root, RandomStreams& streams,
28   ScenarioLowerBound* lower_bound, ScenarioUpperBound* upper_bound,
29   const DSPODM* _sel, History& history, SearchStatistics* statistics) {
30   VNode* cur = root;
31
32   int hist_size = v_stry.Si ?( . . .
33
34   do {
35     if (statistics != NULL)
36       && cur->depth() > statistics->longest_trial_length)
37       statistics->longest_trial_length = cur->depth();
38   }
39
40   ExploitBlockers(cur);
41
42   if (Gap(cur) == 0) {
43     break;
44   }
45
46   if (cur->IsLeaf()) {
47     double start = clock();
48     Expand(cur, lower_bound, upper_bound, model);
49
50     if (statistics != NULL) {
51       statistics->time_node_expansion += (clock() - start) / CLOCKS_PER_SEC;
52       statistics->num_expanded_nodes++;
53       statistics->num_tree_particles += m150;
54     }
55   }
56
57
58   double start = clock();
59   QNode* qstar = SelectBestUpperBoundNode(cur);
60   VNode* next = SelectBestEUNode(qstar);
61
62   if (statistics != NULL) {
63     statistics->time_path += (clock() - start) / CLOCKS_PER_SEC;
64   }
65
66   if (next == NULL) {
67     break;
68   }
69
70   cur = next;
71   history.Add(qstar->edge(), cur->edge());
72 } while (cur->depth() < Globals::config.search_depth);
73
74 history.Truncate(hist_size);
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# Julia - S

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**Algorithm 1** `BUILDDESPOT( $b_0$ )`


---

- 1: Sample randomly a set  $\Phi_{b_0}$  of  $K$  scenarios from the current belief  $b_0$ .
- 2: Create a new DESPOT  $\mathcal{D}$  with a single node  $b_0$  as the root.
- 3: Initialize  $U(b_0)$ ,  $L_0(b_0)$ ,  $\mu(b_0)$ , and  $\ell(b_0)$ .
- 4:  $\epsilon(b_0) \leftarrow \mu(b_0) - \ell(b_0)$ .
- 5: **while**  $\epsilon(b_0) > \epsilon_0$  and the total running time is less than  $T_{\max}$  **do**
- 6:    $b \leftarrow \text{EXPLORE}(\mathcal{D}, b_0)$ .
- 7:    $\text{BACKUP}(\mathcal{D}, b)$ .
- 8:    $\epsilon(b_0) \leftarrow \mu(b_0) - \ell(b_0)$ .
- 9: **return**  $\ell$

---

**Algorithm 2** `EXPLORE( $\mathcal{D}, b$ )`


---

- 1: **while**  $\Delta(b) \leq D$ ,  $E(b) > 0$ , and  $\text{PRUNE}(\mathcal{D}, b) = \text{FALSE}$  **do**
- 2:   **if**  $b$  is a leaf node in  $\mathcal{D}$  **then**
- 3:     Expand  $b$  one level deeper. Insert each new child  $b'$  of  $b$  into  $\mathcal{D}$ . Initialize  $U(b')$ ,  $L_0(b')$ ,  $\mu(b')$ , and  $\ell(b')$ .
- 4:      $a^* \leftarrow \arg \max_{a \in A} \mu(b, a)$ .
- 5:      $z^* \leftarrow \arg \max_{z \in Z_{b, a^*}} E(\tau(b, a^*, z))$ .
- 6:      $b \leftarrow \tau(b, a^*, z^*)$ .
- 7:   **if**  $\Delta(b) > D$  **then**
- 8:      $\text{MAKedefault}(b)$ .
- 9: **return**  $b$ .

---

**Algorithm 4** `PRUNE( $\mathcal{D}, b$ )`


---

- 1:  $\text{BLOCKED} \leftarrow \text{FALSE}$ .
- 2: **for** each node  $x$  on the path from  $b$  to the root of  $\mathcal{D}$  **do**
- 3:   **if**  $b'$  is blocked by any ancestor node in  $\mathcal{D}$  **then**
- 4:      $\text{MAKedefault}(x)$ .
- 5:      $\text{BACKUP}(\mathcal{D}, x)$ .
- 6:      $\text{BLOCKED} \leftarrow \text{TRUE}$ .
- 7:   **else**
- 8:     **break**
- 9: **return**  $\text{BLOCKED}$

---

```

1 function build_despot(p::DESPOTPlanner, b_0)
2   D = DESPOT(p, b_0)
3   b = 1
4   trial = 1
5   start = CPUtime_us()
6
7   while D.mu[1]-D.l[1] > p.sol.epsilon_0 &&
8     CPUtime_us()-start < p.sol.T_max*1e6 &&
9       trial <= p.sol.max_trials
10      b = explore!(D, 1, p)
11      backup!(D, b, p)
12      trial += 1
13    end
14
15  return D
16 end
17
18 function explore!(D::DESPOT, b::Int, p::DESPOTPlanner)
19   while D.Delta[b] <= p.sol.D &&
20     excess_uncertainty(D, b, p) > 0.0
21     && !prune!(D, b, p)
22
23     if isempty(D.children[b]) # a leaf
24       expand!(D, b, p)
25     end
26     b = next_best(D, b, p)
27   end
28   if D.Delta[b] > p.sol.D
29     make_default!(D, b)
30   end
31   return b
32 end
33
34 function prune!(D::DESPOT, b::Int, p::DESPOTPlanner)
35   x = b
36   blocked = false
37   while x != 1
38     n = find_blocker(D, x, p)
39     if n > 0
40       make_default!(D, x)
41       backup!(D, x, p)
42       blocked = true
43     else
44       break
45     end
46     x = D.parent_b[x]
47   end
48   return blocked
49 end

```

# How does it work?

# Speed: Just-in-time LLVM Compilation

