



UNIVERSITY OF CALIFORNIA, IRVINE  
MOZILLA RESEARCH

---

# PARALLEL PERFORMANCE-ENERGY PREDICTIVE MODELING OF BROWSERS: CASE STUDY OF SERVO

Rohit Zambre, Lars Bergstrom, Laleh Aghababaie Beni, Aparna Chandramowlishwaran

**2,200,000**

2,200,000

Google Play Store, June 2016

## A SMART BUT CLUTTERED PHONE

- ▶ “Free” apps not really free
- ▶ Cost memory
- ▶ One gatekeeper



ONE  
App?



Facebook Login Screen

facebook

Heading out? Stay connected Visit facebook.com on your mobile phone.

Sign Up It's free and always will be.

First Name: [ ] Last Name: [ ] Your Email: [ ] Re-enter Email: [ ] New Password: [ ] I am: [Select Sec] Birthday: [Month: Day: Year: ] Why do I need to provide this? Sign Up Create a Page for a celebrity, band or business.

Email (US) Español Português (Brazil) Français (France) Deutsch Italiano Aziendale 中文 (简体) 日本語



lumosity

Your Brain Profile

Memory Games

Memory Matrix, Memory Match, Moneycomb, Monster Garden, Name Tag

LUMINOSITY POINTS: Overall: 100% complete, 1000 points

LUMINOSITY POINTS: Compton Section 40 of Attention Boost: +2, Train Focus with Lost in Thought: +1, Train Visual Field with Brainweaving: +1

TYPES OF MEMORY: Spatial Recall, Working Memory

Spatial Recall: • Sense of 3-D environment, • Remembering location of things, • Recognizing visual patterns, • Read More

Working Memory: • Learning and reasoning, • IQ and intelligence

Other games related to Memory: Spatial Speed, Top Glass, Speed Match, Information Processing, Working Memory



# ONE App?

Inbox (13,953)

Compose

Primary

Import

Sort Mail

Drafts

All Mail

Spam

Trash

[Inbox] Drafts

Search people...

↳ [ ] Gmail

↳ [ ] Google

↳ [ ] Social Updates, Meetup, Showcases

↳ [ ] Promotions

↳ [ ] Walmart

↳ [ ] The PayParks Team

↳ [ ] Amazon.com

↳ [ ] Kenneth Copeland Minist.

↳ [ ] Pandora

↳ [ ] GodTube Must-See Video

↳ [ ] Viking River Cruises

↳ [ ] Denic State, Google

↳ [ ] Shopaholic Deal of the...

↳ [ ] Daily Journey

↳ [ ] zounds News

↳ [ ] Alternative View

↳ [ ] Love Worth Finding

↳ [ ] Greg Laurie Daily Devotion

↳ [ ] Walmart

↳ [ ] Google

↳ [ ] Social Updates, Meetup, Showcases

↳ [ ] Promotions

↳ [ ] Save on last-minute gifts today - Forget someone? Email an eGift Card in a flash! My account Walmart - Save Money Live Better

Happy Holidays from PayParks! - Learning, Earring, Whining View this email in your browser

Kirk Schmidling: Year-End Deals - Kirk Schmidling, we have recommendations for you. FREE One-Day Shipping on Top Gif Ideas Amazon.com

Kenneth Copeland: Kick start 2014 with the January Believer's Voice of Victory magazine! - Having trouble viewing this email? Click here. Dear Kirk, We are happy to see you again!

The key to Bates - View Online | Contact Us PANDORA The best way to listen to your favorite Holiday songs. Ad-Free

GodTube: You Don't Believe How this 2-Year Old Works the Loudest Amazing - Click here to view in your browser. Don't miss videos like Funny Church Signs, Pray

Get up to FREE air to Russia or Ukraine - Discover Russia and Ukraine in October 2014 Smartphone version click here 2-for-1 cruise plus up to

Get the most out of Google+ - Google Goodness, Kirk We did it. More than 107000 people signed the "I'm the People"

Deals success! Next step is to ECPA rules - Google Goodness, Kirk We did it. More than 107000 people signed the "I'm the People"

Deal Alert from Shopaholic Deal of the Day - Hi Shopaholic Customer, Deal Alert Here's Today's Deal of the Day: personalized deals

Daily Journey from the John Ankerberg Show - View this Message in a Browser | Forward to a Friend | Unsubscribe

Get the Perfect Gift There's Still Time! - Grab a Gift Certificate today! Help the medicines in your life get the gear they'll love. PLAY AD

Alternative View with Dr. Tony Evans - View this Message in a Browser | Forward to a Friend | Unsubscribe

Love Worth Finding - View this Message in a Browser | Forward to a Friend | Unsubscribe

Greg Laurie Daily Devotion - View this Message in a Browser | Forward to a Friend | Unsubscribe

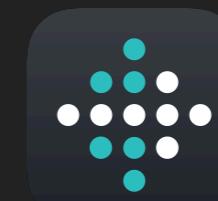
Walmart

Google

Social Updates, Meetup, Showcases

Promotions

132 PM 12/20/2013



Introducing Force. Your fitness stats + time, now on display.

fitbit

Dashboard Log Community Premium STORE

TODAY January 24

Steps: 2,285

Very Active Mins: 7 min

Activity: STEPS CALORIES FLOORS

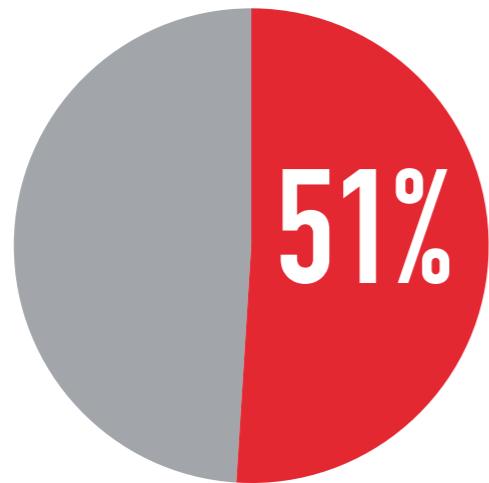
Friends: Mike M. 139,519, You 78,133, Jim McCain 69,015, Julie 28,456

Distance / miles: 1.01

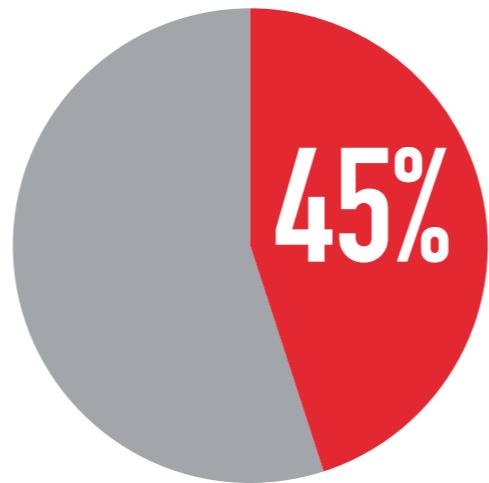
Calories: 831

Floors: 0

## PROBLEMS WITH THE MOBILE BROWSER

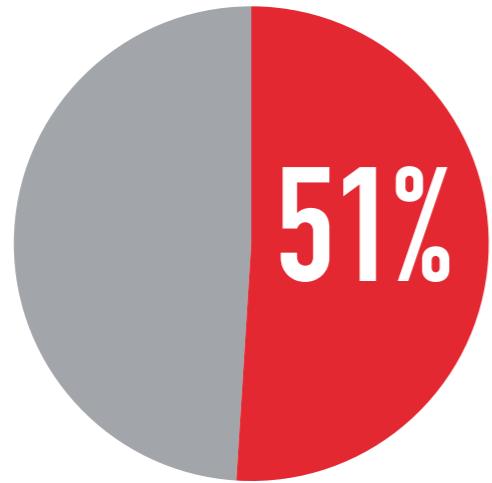


Crashed

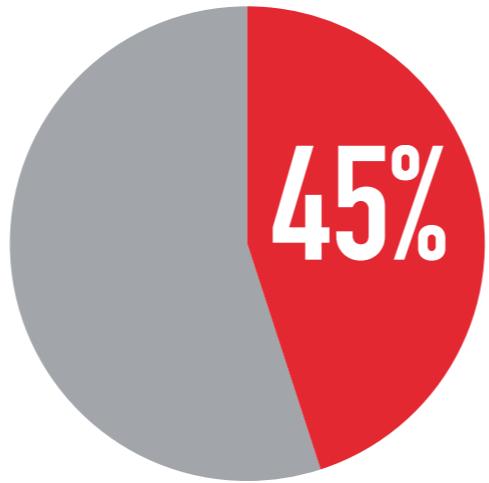


Unexpected

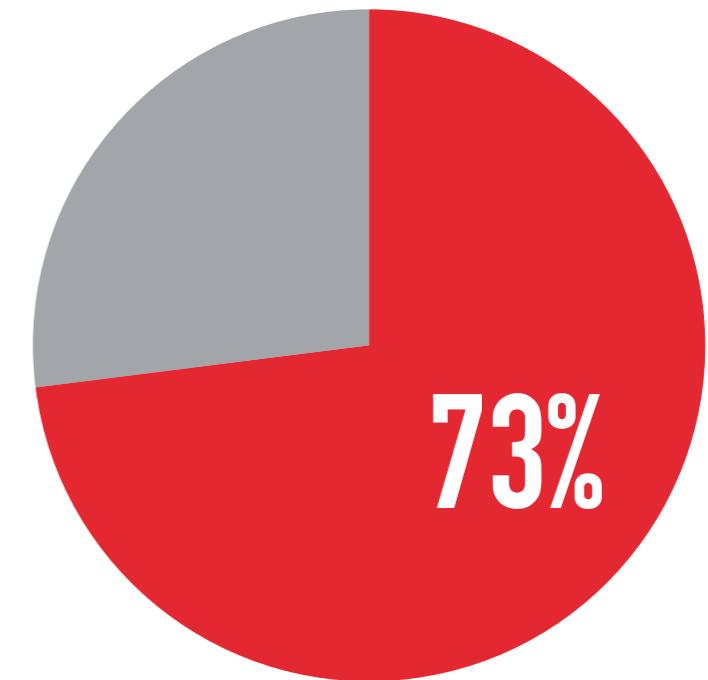
## PROBLEMS WITH THE MOBILE BROWSER



Crashed



Unexpected



Too Slow

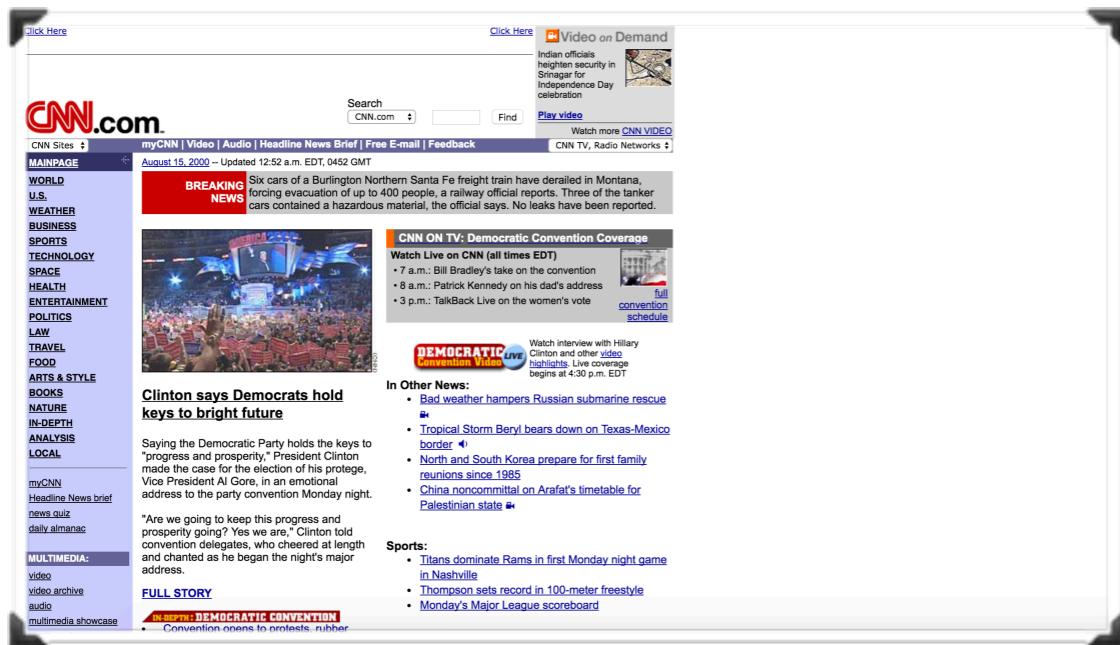
## WHY SLOW?

- ▶ Fundamental architecture unchanged since 1990s

# PARALLEL PERFORMANCE-ENERGY PREDICTIVE MODELING OF BROWSERS

## WHY SLOW?

- ▶ Fundamental architecture unchanged since 1990s

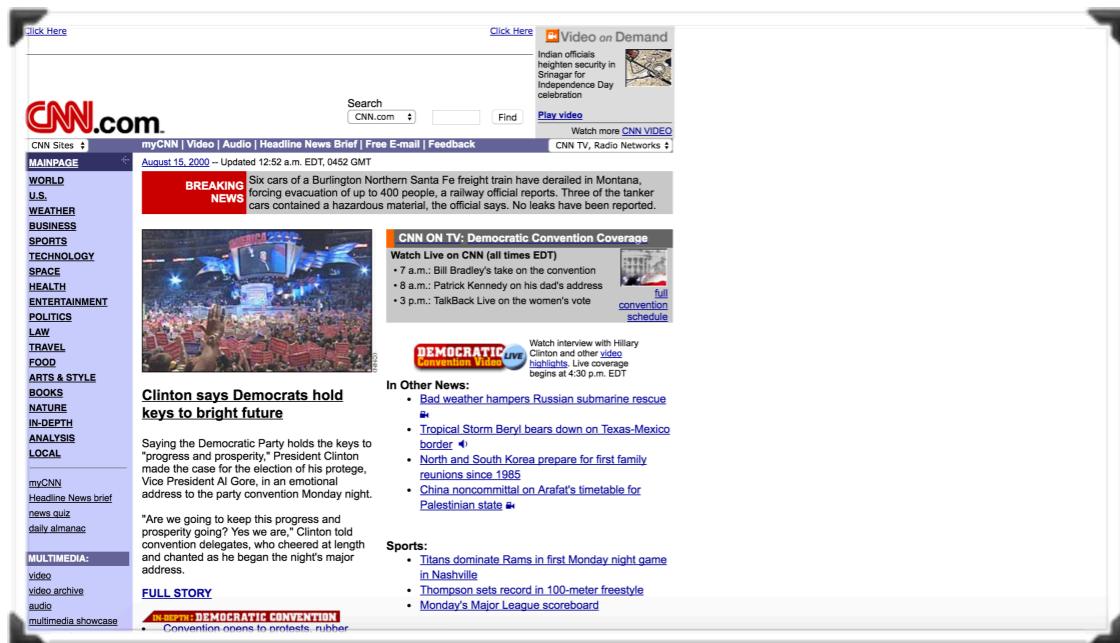


2000

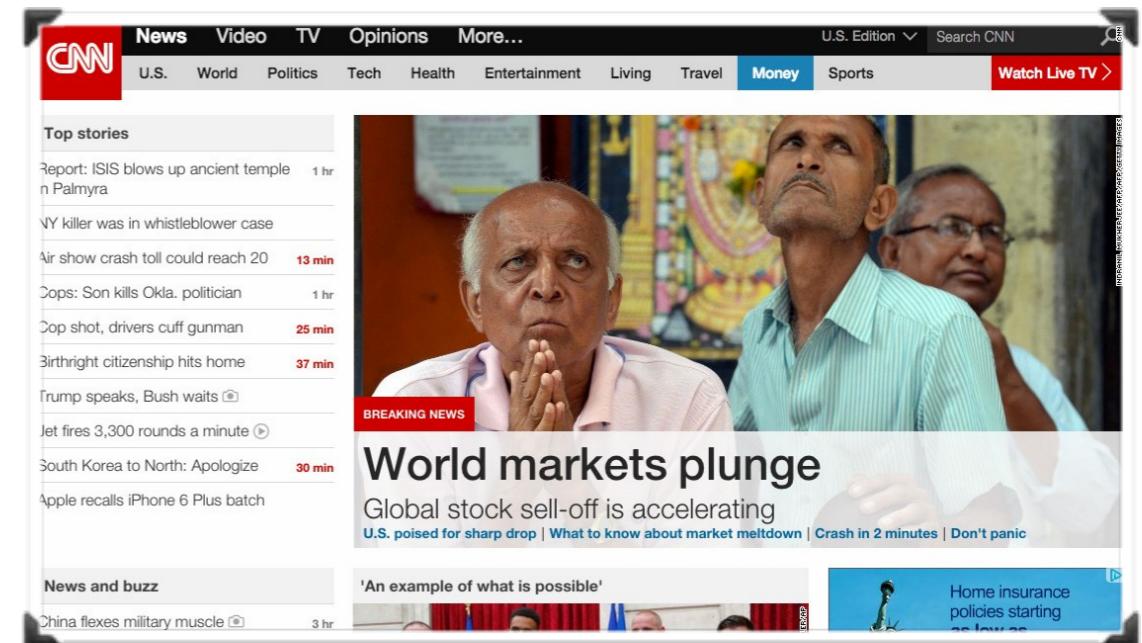
# PARALLEL PERFORMANCE-ENERGY PREDICTIVE MODELING OF BROWSERS

## WHY SLOW?

- ▶ Fundamental architecture unchanged since 1990s



2000



2016

## WHY SLOW?

- ▶ Web page complexity continually increasing
- ▶ Fundamental architecture unchanged since 1990s
  - ▶ Only sequential optimizations
  - ▶ Incremental feature support

# OBJECTIVE

# MAKE THE BROWSER FASTER

# OBJECTIVE

MAKE THE  
BROWSER FASTER

Revive the Universal Web  
platform.

# HOW TO MAKE IT FASTER?

# HOW TO MAKE IT FASTER?

# PARALLELIZE BROWSER TASKS

## RELATED WORK

- ▶ Parallelizing browser tasks:
  - ▶ Styling: Meyerovich et al. (80x) [28], Badea et al. (1.8x) [21]
  - ▶ Parsing: Zhao et al. (2.4x) [34]

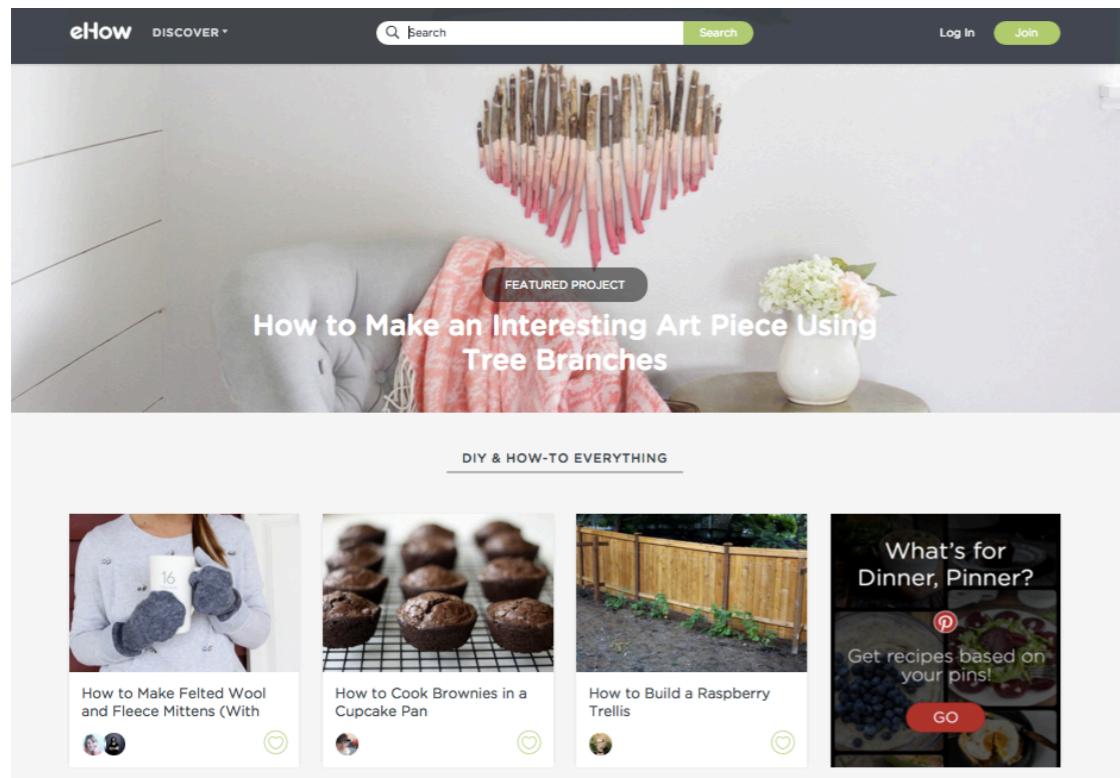
## RELATED WORK

- ▶ Parallelizing browser tasks:
  - ▶ Styling: Meyerovich et al. (80x) [28], Badea et al. (1.8x) [21]
  - ▶ Parsing: Zhao et al. (2.4x) [34]
- ▶ Concurrent/Parallel Browsers:
  - ▶ Concurrent: Google Chrome, Mozilla Firefox
  - ▶ Parallel + Concurrent: Qualcomm's ZOOMM (2x)

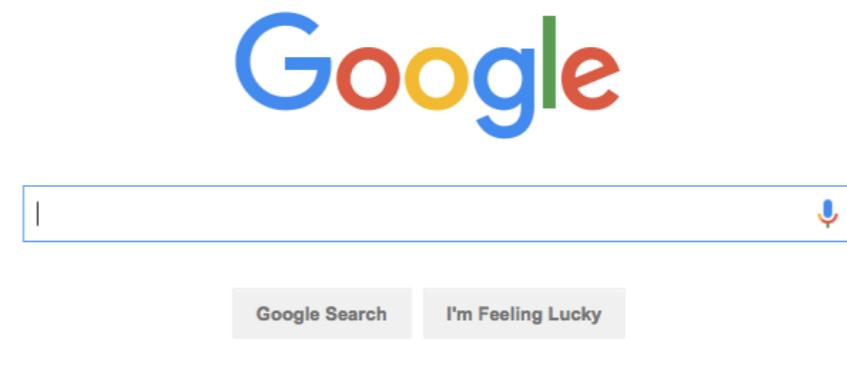
THE WORKLOAD OF A  
BROWSER IS DEPENDENT ON  
THE PAGE IT IS RENDERING.

Browser Internals

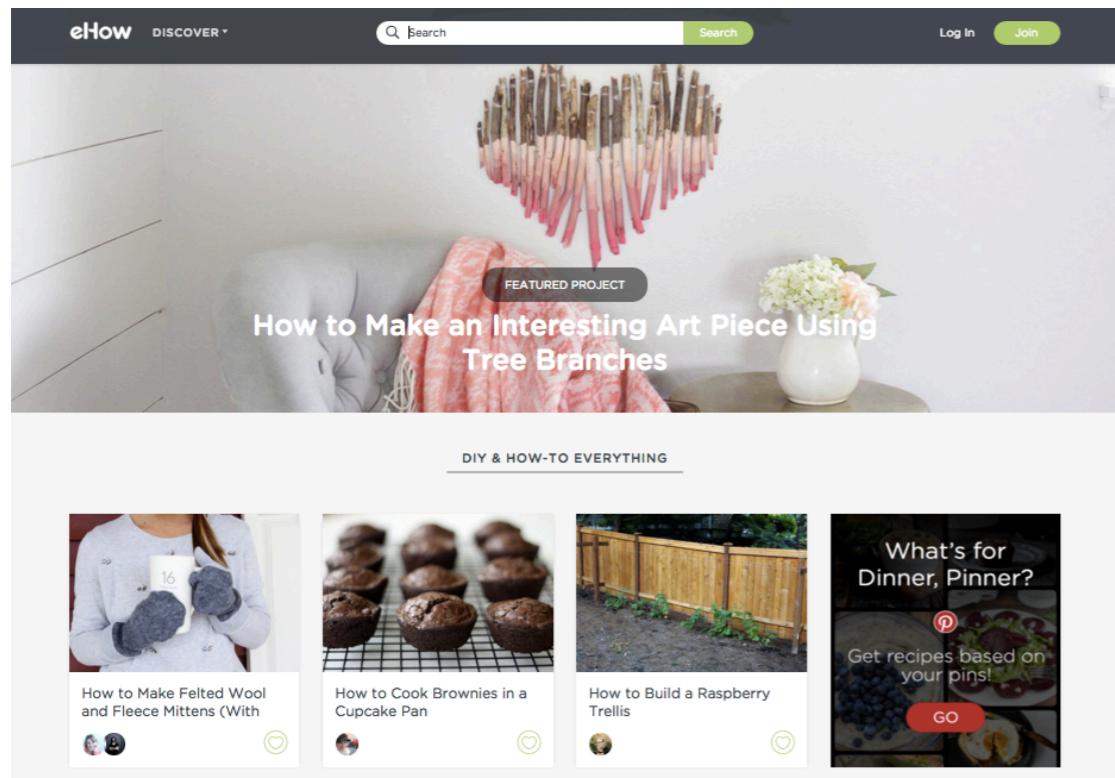
## WORKLOAD VARIETY



PARALLEL OVERHEAD



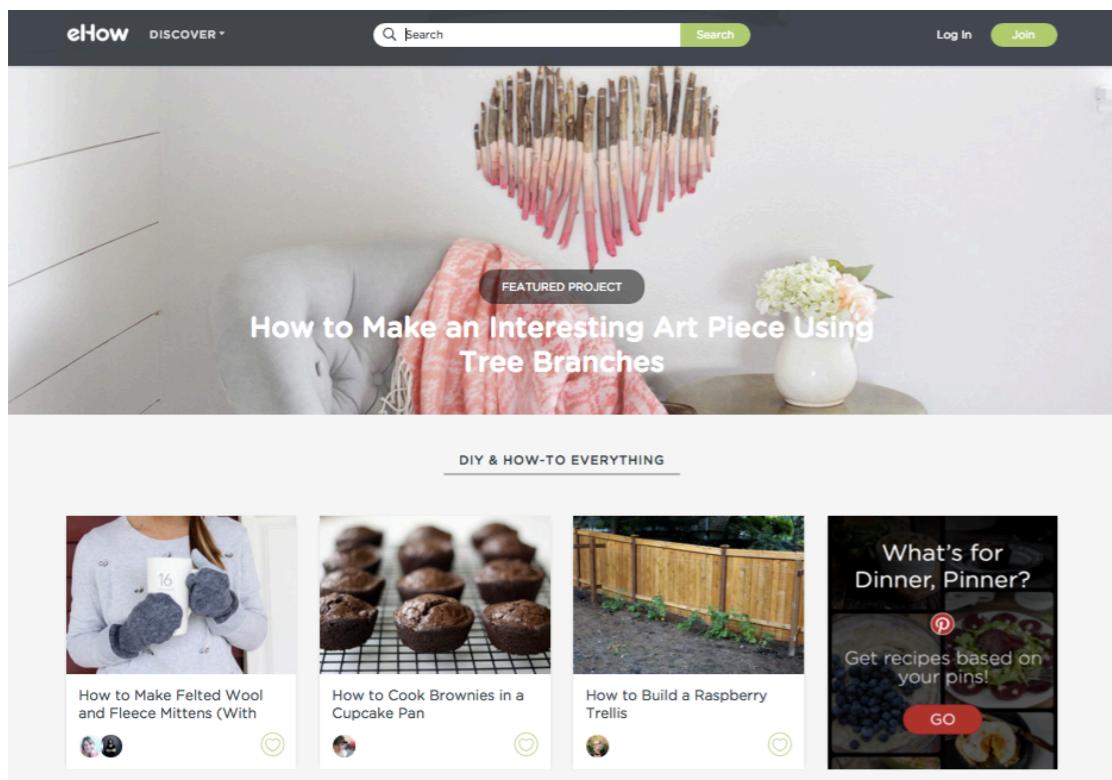
## WORKLOAD VARIETY



• • •

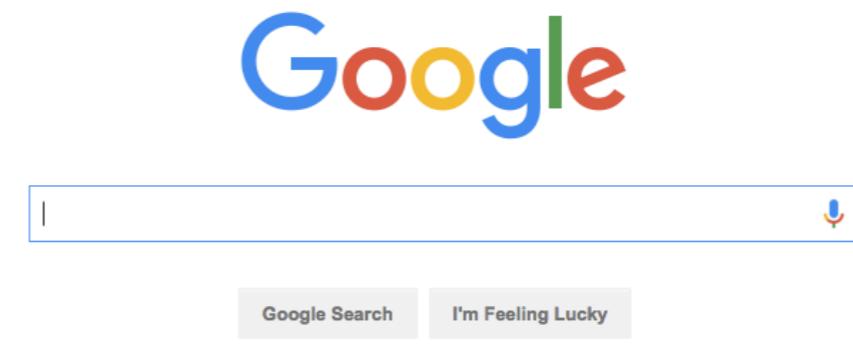


## WORKLOAD VARIETY



Creation, deletion, coordination

PARALLEL OVERHEAD



**OUR IDEA**

**ADAPTIVE  
PARALLELISM**

## HOW DO WE ADAPTIVELY PARALLELIZE?

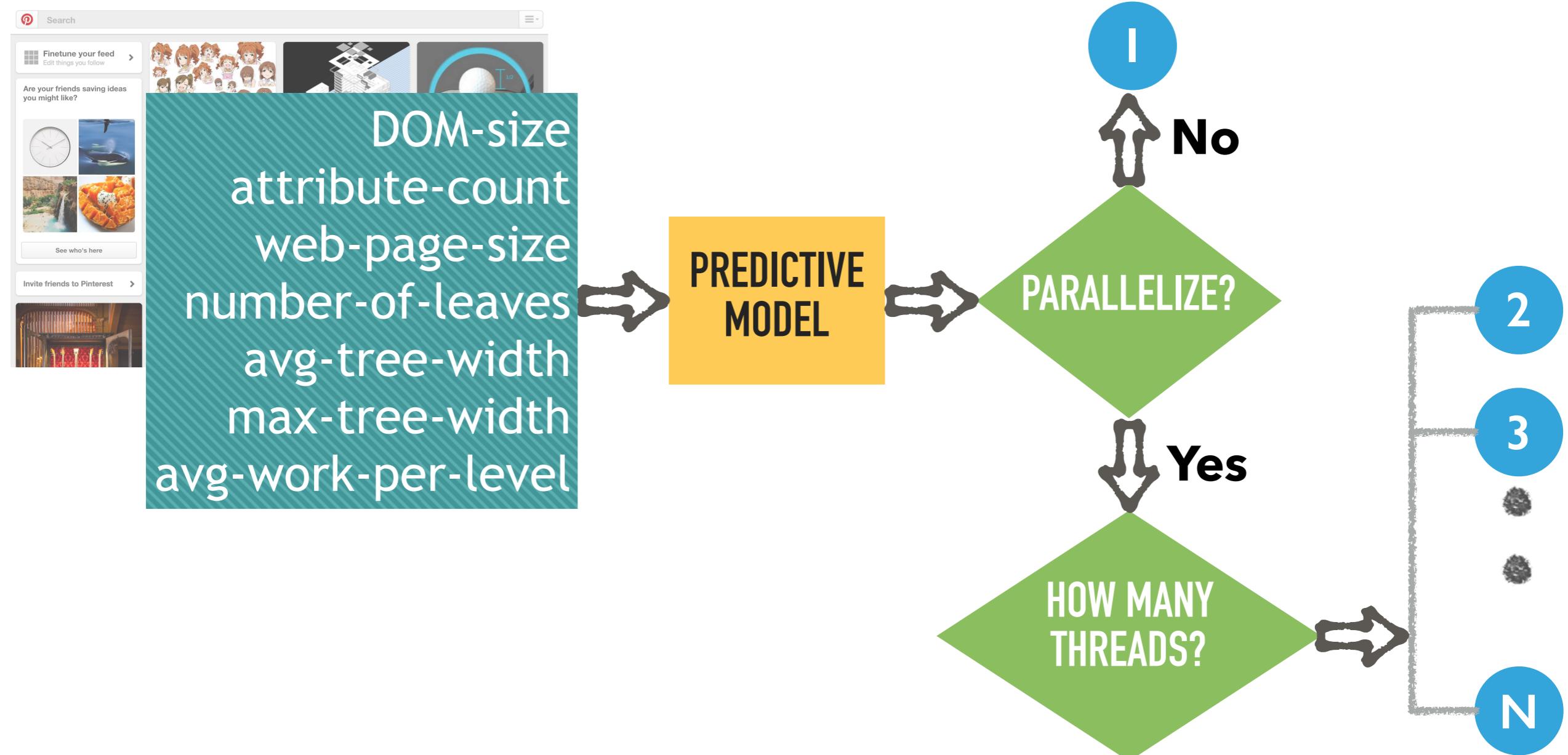
### HOW DO WE ADAPTIVELY PARALLELIZE?

- ▶ Using predictive models of a browser's parallel performance and energy

### HOW DO WE ADAPTIVELY PARALLELIZE?

- ▶ Using predictive models of a browser's parallel performance and energy
- ▶ Generated using machine learning techniques

## HOW TO USE SUCH A MODEL?



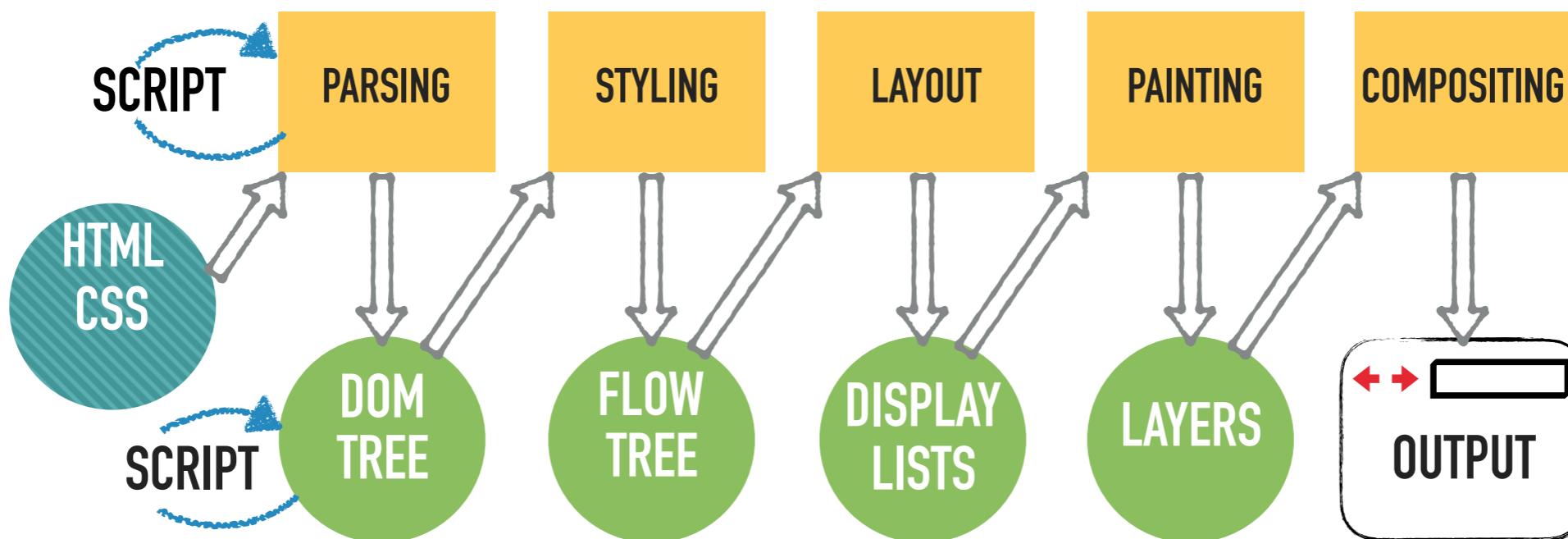
## OUR CONTRIBUTIONS

- ▶ Implementation-blind workload characterization
- ▶ Automated labeling algorithms
- ▶ Model generation and prediction

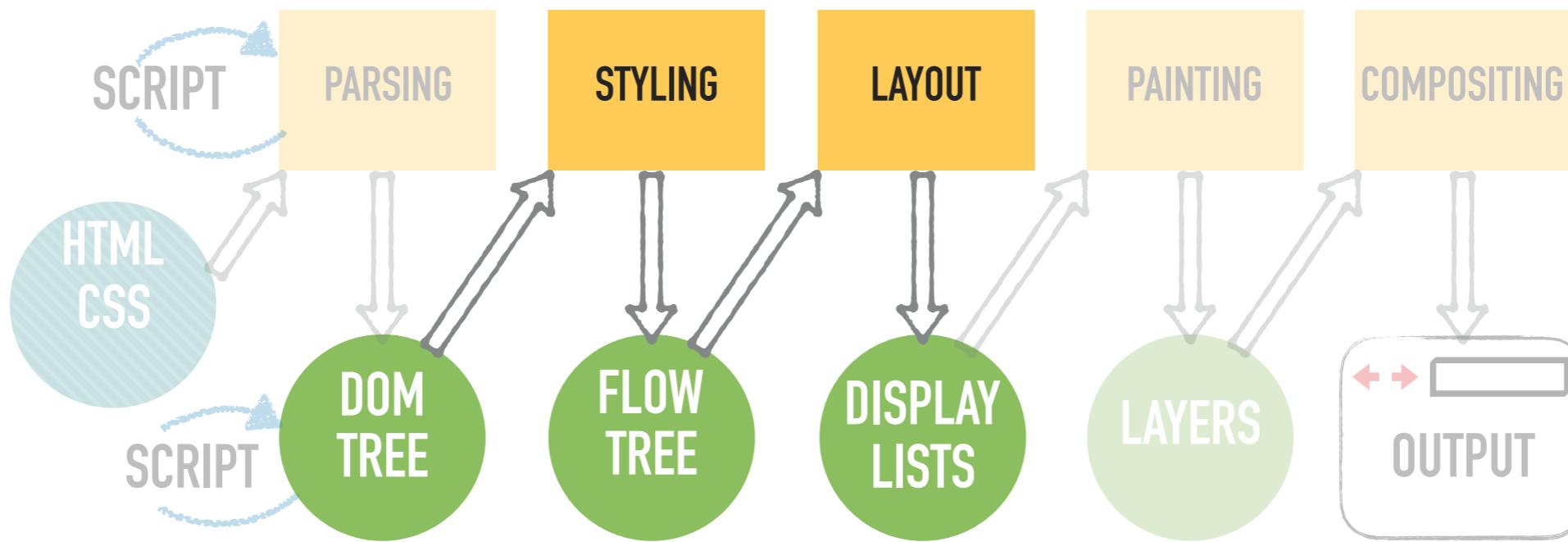
## OUR CONTRIBUTIONS

- ▶ Implementation-blind workload characterization
- ▶ Automated labeling algorithms
- ▶ Model generation and prediction
- ▶ Extendable to any parallel browser on any platform
  - ▶ Configurable thread configurations, labeling

## PARALLEL BROWSER INTERNALS

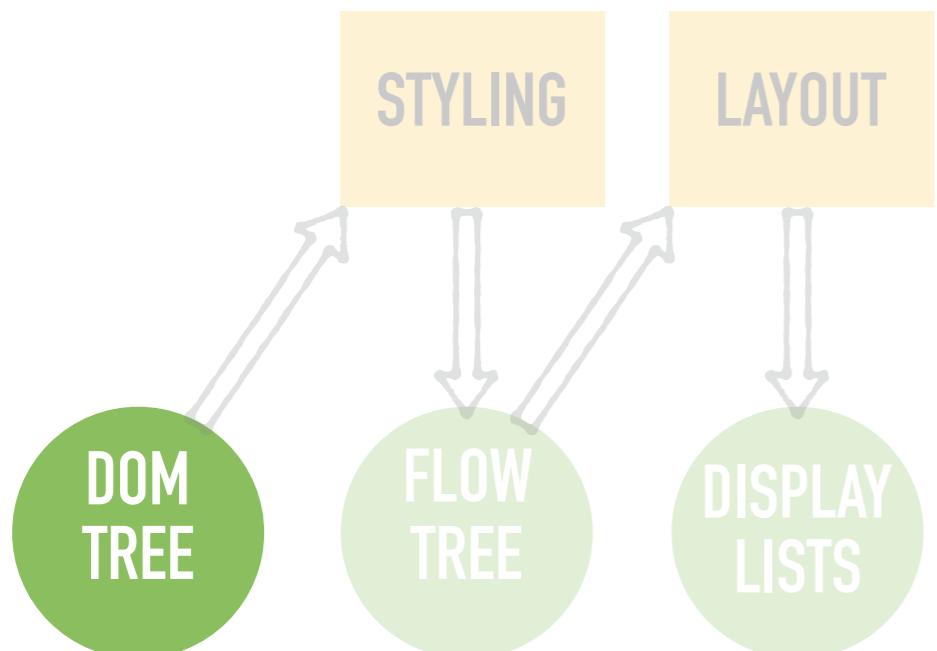


## PARALLEL BROWSER INTERNALS

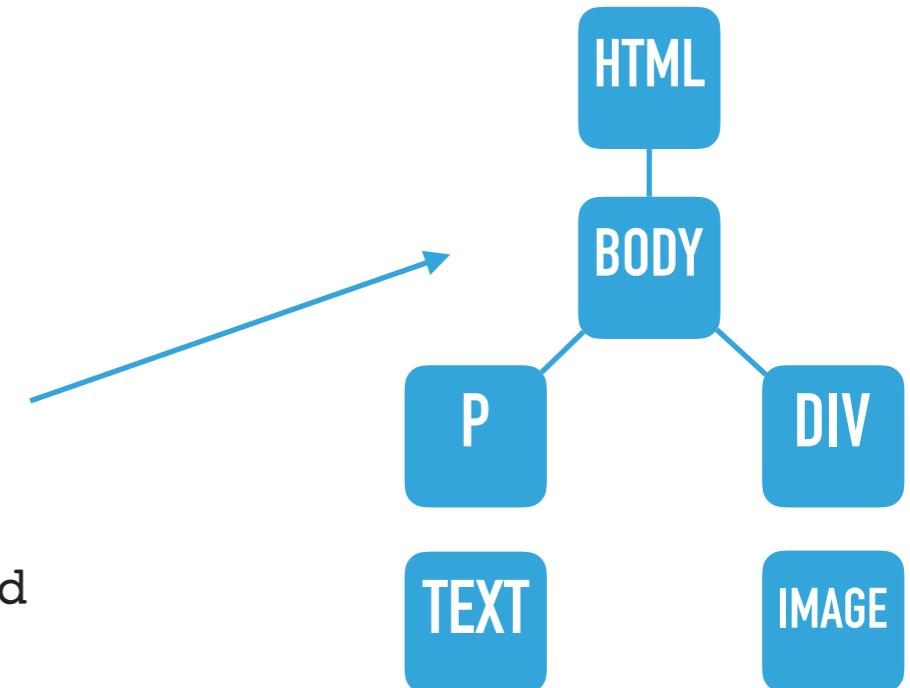


Styling + Layout = Overall Layout is most computationally intensive

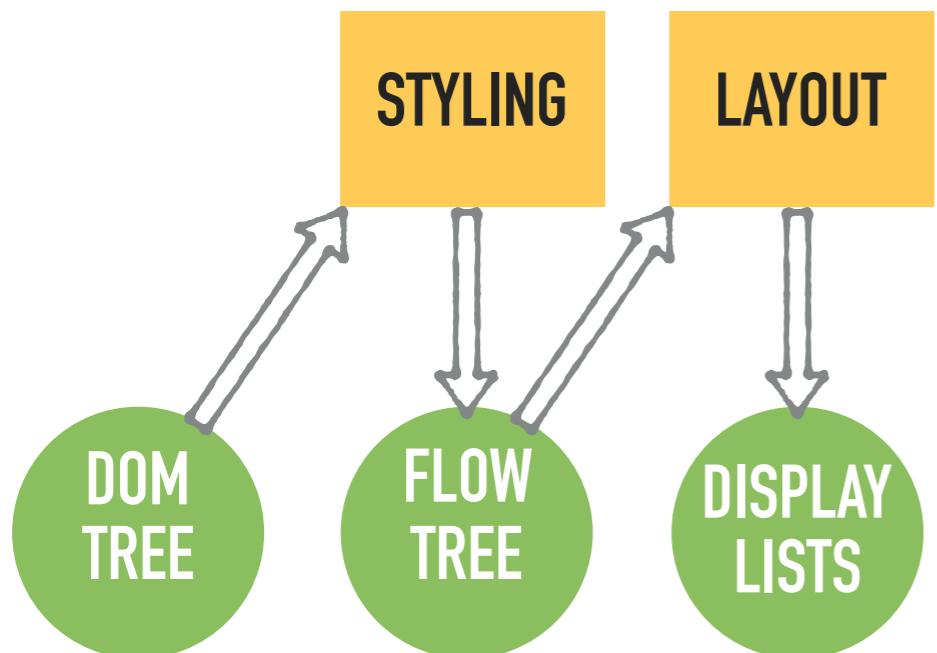
## PARALLEL BROWSER INTERNALS



```
<html>
  <body>
    <p>
      Hello World
    </p>
    <div> </div>
  </body>
</html>
```

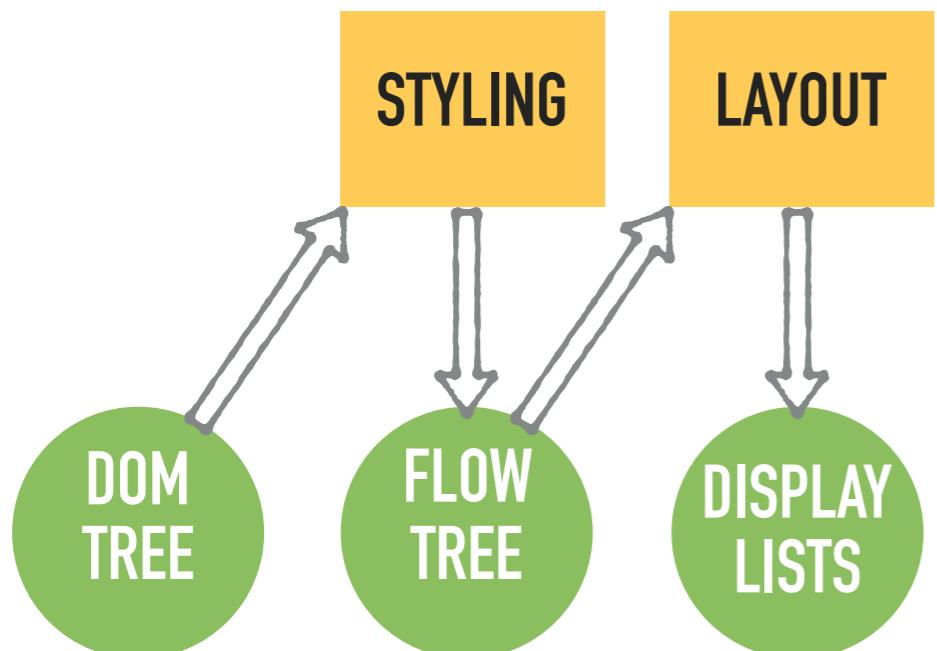


## PARALLEL BROWSER INTERNALS



- ▶ Styling: attach styles to DOM tree nodes
- ▶ Layout: compute absolute geometric dimensions

## PARALLEL BROWSER INTERNALS



- ▶ Multiple *DOM* nodes can be styled simultaneously
- ▶ Parallel, consecutive top-down and bottom-up tree traversals
- ▶ Meyerovich et al. [28]

## MOZILLA RESEARCH'S SERVO

[servo / servo](#)

Code Issues 1,847 Pull requests 73 Projects 0 Wiki Pulse Graphs

The Servo Browser Engine <https://servo.org/>

22,021 commits 36 branches 1 release 624 contributors MPL-2.0

Branch: master New pull request Find file Clone or download ▾

bors-servo committed on GitHub Auto merge of #14445 - mrnayak:netSecurity, r=jdm ... Latest commit b05c27c 4 hours ago

File	Commit Message	Time Ago
components	Auto merge of #14445 - mrnayak:netSecurity, r=jdm	4 hours ago
docs	Remove SelectorImpl aliases	13 days ago
etc	Add an option to submit test-perf result to perfherder	4 days ago
ports	stylo: Add FFI function to check if a node is dirty.	2 days ago
python	Auto merge of #14452 - PeterZhizhin:upgrade-pip-with-new-virtualenv, ...	22 hours ago
resources	Auto merge of #14286 - gterzian:update_canvas_with_offscreen_context,...	10 days ago
support	Remove unused font config from wxs	21 days ago
tests	Auto merge of #14445 - mrnayak:netSecurity, r=jdm	4 hours ago
.gitattributes	Appease Github's Linguist	2 years ago
.gitignore	Move ports/geckolib/target to target/geckolib	5 months ago

- ▶ Written in Rust
- ▶ Uses work-stealing scheduler
- ▶ Sequential *Overall Layout* is 2x faster than Firefox's
- ▶ High parallel speedups
  - ▶ 3.2x, 2.5x with 4 threads on [humana.com](http://humana.com), [kohls.com](http://kohls.com)

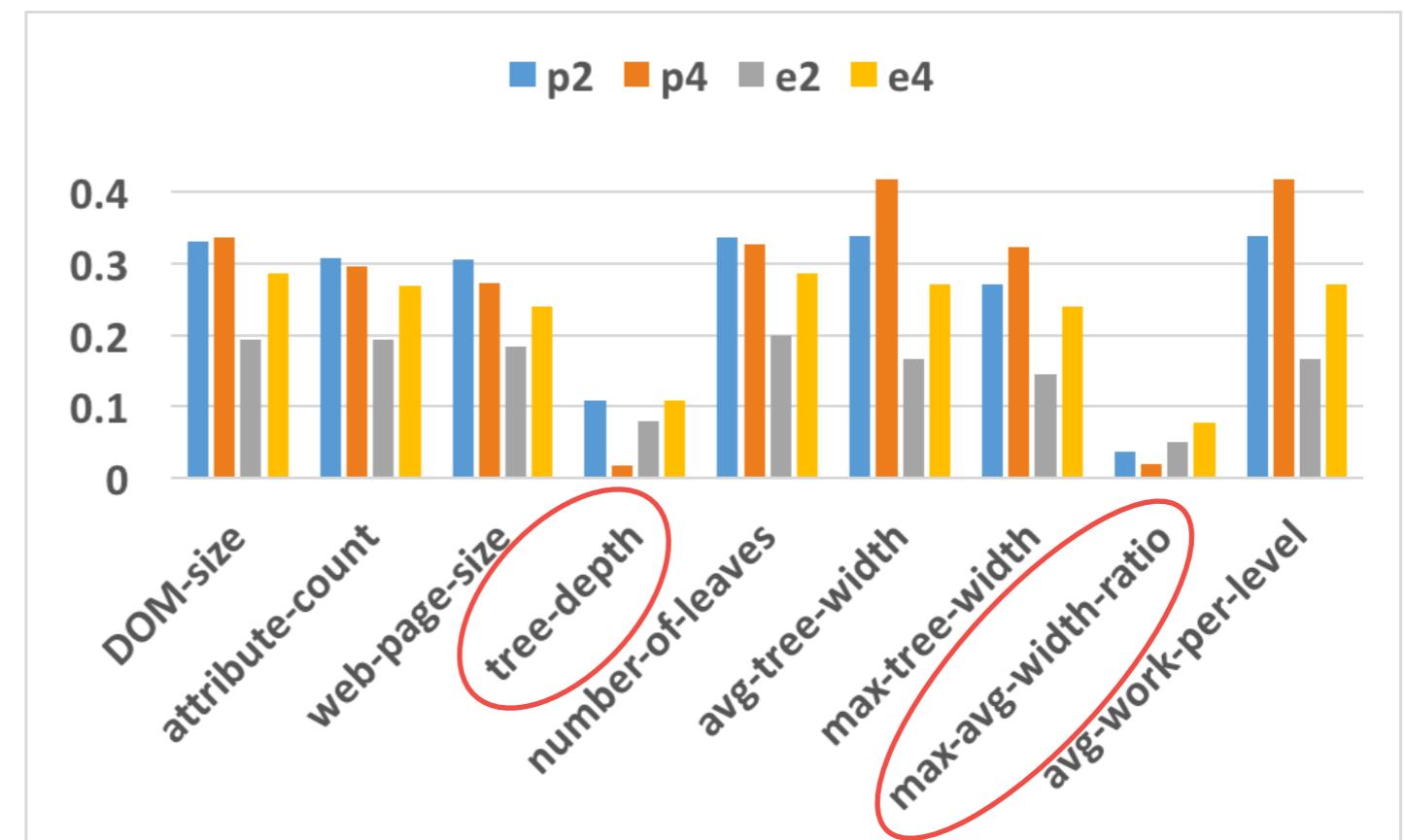
## WORKLOAD CHARACTERIZATION

- ▶ DOM tree characteristics intuitively predict available parallelism
- ▶ Looked at 9 features
- ▶ Used 7 features

## WORKLOAD CHARACTERIZATION

- ▶ DOM tree characteristics intuitively predict available parallelism
- ▶ Looked at 9 features
- ▶ Used 7 features

**Correlation between  
DOM-tree features and  
parallel work**



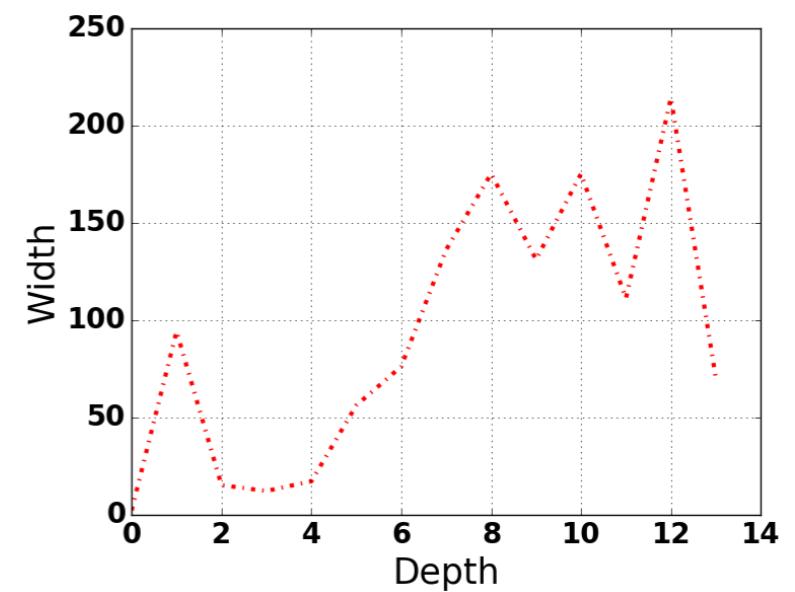
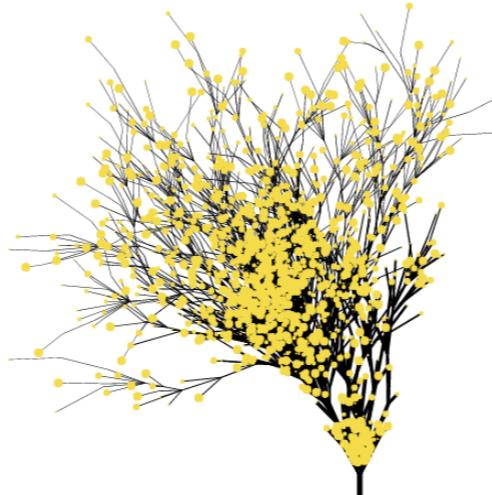
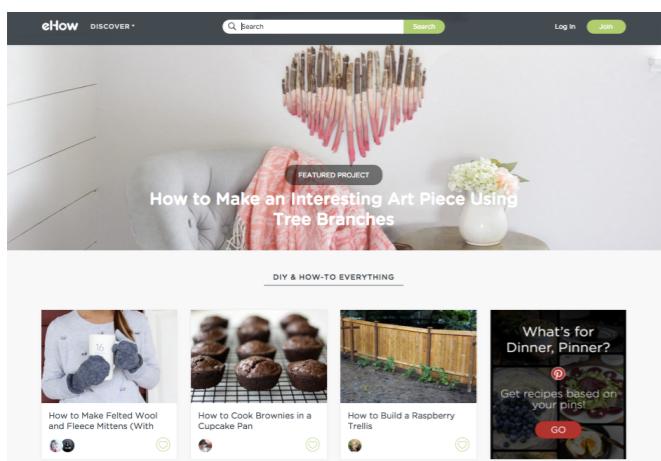
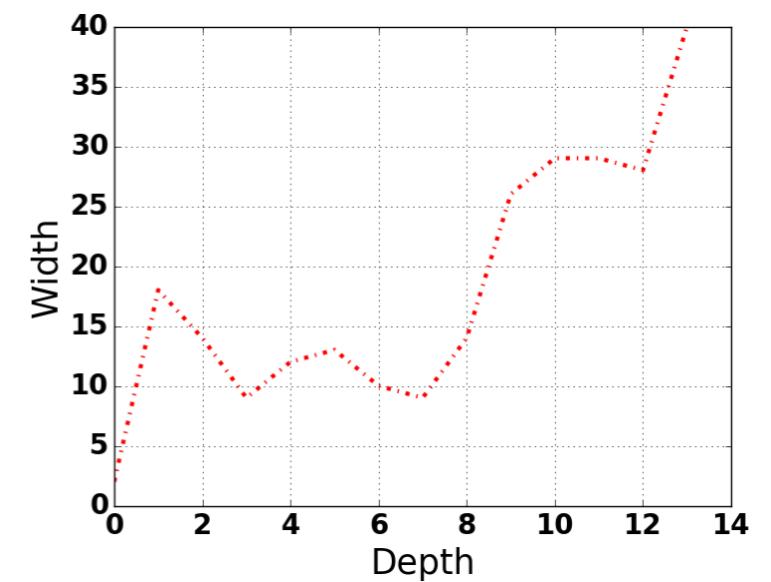
## WORKLOAD CHARACTERIZATION

- ▶ **DOM-size**: total number of nodes in the DOM tree
- ▶ **attribute-count**: total number of attributes in HTML tags
- ▶ **web-page-size**: size of the web pages' HTML (bytes)
- ▶ **number-of-leaves**: number of leaves in DOM tree
- ▶ **avg-tree-width**: average number of nodes at a level of tree
- ▶ **max-tree-width**: largest number of nodes at a level of tree
- ▶ **avg-work-per-level**: average work per level of tree

## WORKLOAD CHARACTERIZATION

- ▶ **DOM-size:** total number of nodes in the DOM tree
- ▶ **attribute-count:** total number of attributes in HTML tags
- ▶ **web-page-size:** size of the web pages' HTML (bytes)
- ▶ **number-of-leaves:** number of leaves in DOM tree
- ▶ **avg-tree-width:** average number of nodes at a level of tree
- ▶ **max-tree-width:** largest number of nodes at a level of tree
- ▶ **avg-work-per-level:** average work per level of tree

## WORKLOAD CHARACTERIZATION



## PREPARE TRAINING DATA

- ▶ Define thread-configurations

$$T = \{ t \mid t \text{ is a thread-configuration} \}$$

- ▶ For each web page

- ▶ Collect performance and energy usage with  $|T|$  thread-configurations

- ▶ Speedup + Greenup  $\forall t \in T$

$p_t$

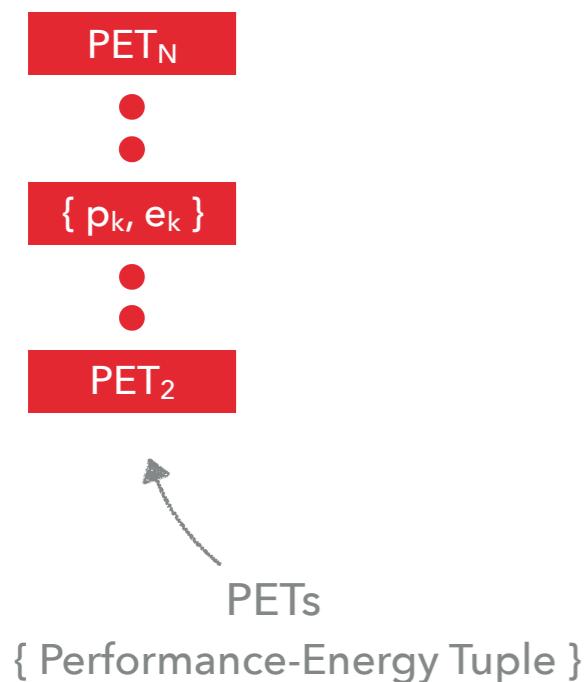
$e_t$

- ▶ Label using a cost model

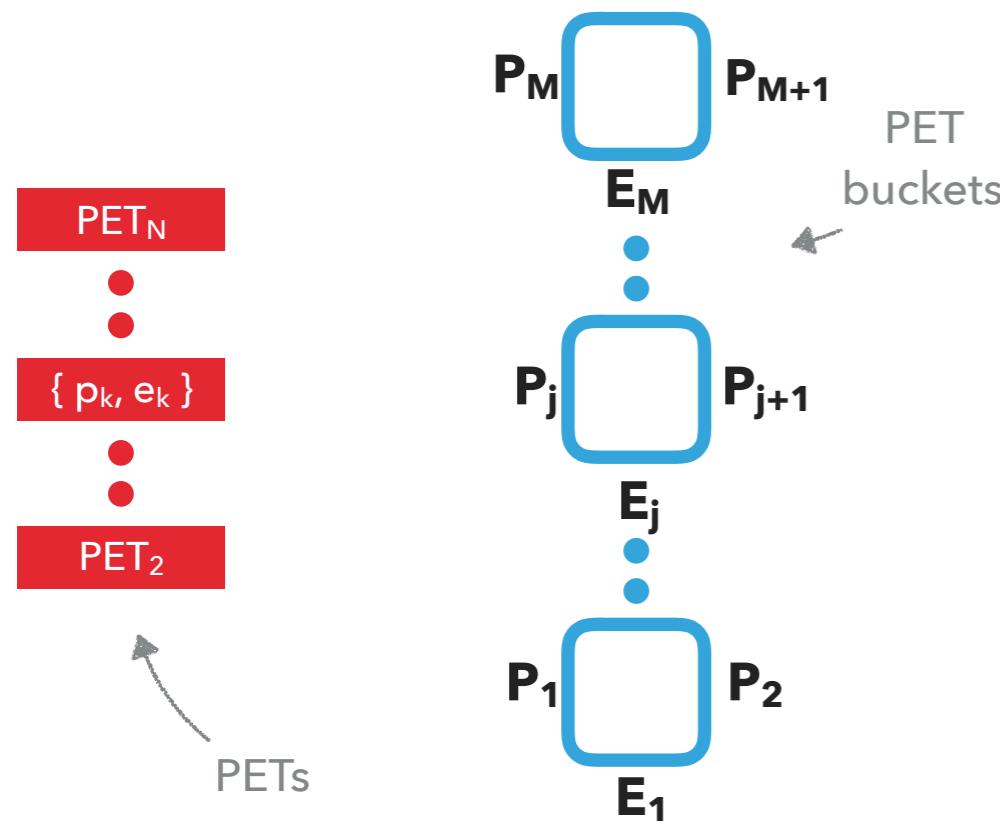
## AUTOMATED LABELING

- ▶ Performance and Energy Cost Model
  - ▶ Label a web page

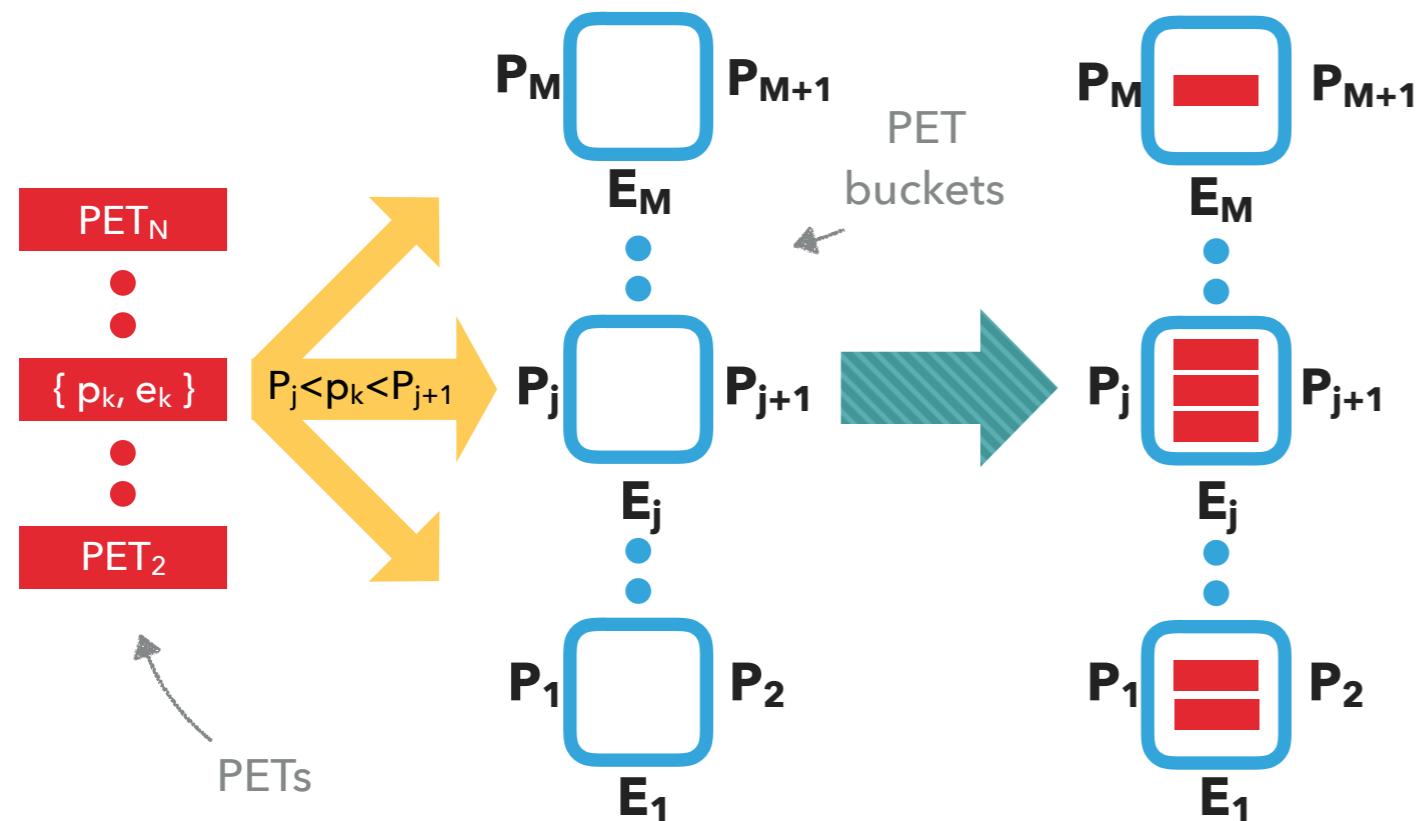
## AUTOMATED LABELING



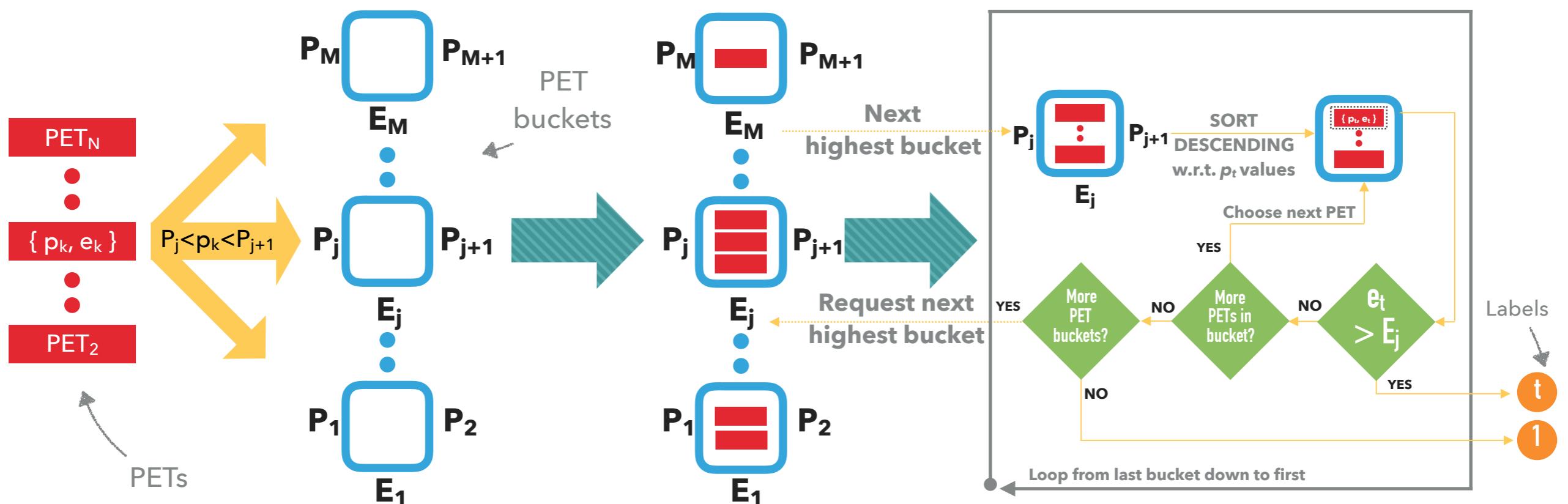
## AUTOMATED LABELING



## AUTOMATED LABELING



## AUTOMATED LABELING



### CASE STUDY WITH SERVO

- ▶ **Testbed:** Quad-core Intel i7 Ivy Bridge; 8GB RAM; OS X 10.9
- ▶ **Thread-configurations:** 1, 2, 4
- ▶ **Samples:** 535 webpages from *Alexa Top 500 + 2012 Fortune 1000*
- ▶ Google's *Web Page Replay* to maintain repeatability
- ▶ Performance measurements with Servo's internal instrumentation
- ▶ Energy measurements with Apple's *powermetrics*

## SUPERVISED LEARNING

- ▶ Off-the-shelf learning techniques to train the model
- ▶ Confident accuracies

<b><i>Supervised Learning Algorithm</i></b>	<b><i>Evaluation Method</i></b>	<b><i>Average Accuracy</i></b>	<b><i>Maximum Accuracy</i></b>
<b>Multinomial Logistic Regression (MNR)</b>	Cross-validation	72.22%	<b>87.27%</b>
<b>Ensemble Learning</b>	Cross-validation	71.12%	<b>85.45%</b>
<b>Neural Network</b>	Holdout-set	<b>77.8%</b>	-

### OUR MODEL VS SERVO

- ▶ Up to **94.52%** performance savings
  - ▶ 2.48 ms with 1 thread vs. 45.41 ms with 4 threads ([indeed.com](http://indeed.com))
- ▶ Up to **46.32%** energy savings
  - ▶ 84.88 J with 1 thread vs. 158.14 J with 4 threads ([starbucks.com](http://starbucks.com))
- ▶ Predict rightly when we need to use 4 threads
  - ▶ 2.15x speedup, 1.17x greenup with 4 threads ([booking.com](http://booking.com))
- ▶ 2 threads better than 4 threads
  - ▶ 1.36x with 2 threads vs. 1.21x with 4 threads ([creditkarma.com](http://creditkarma.com))

## FUTURE WORK

- ▶ Guided, work-load aware scheduling
  - ▶ Static + Dynamic
- ▶ Modeling on big.LITTLE architecture
- ▶ Modeling parallelism of other browser tasks

## CONCLUSION

- ▶ Adaptive parallelism is key
- ▶ Platform-agnostic modeling technique
  - ▶ using key DOM characteristics
- ▶ Automated labeling algorithms
- ▶ Robust accuracies and savings
- ▶ Productive step towards reviving the universal Web platform

We thank IEEE TCPP for providing travel support to attend IEEE HiPC 2016

# THANK YOU!

Rohit Zambre

PhD, Computer Engineering

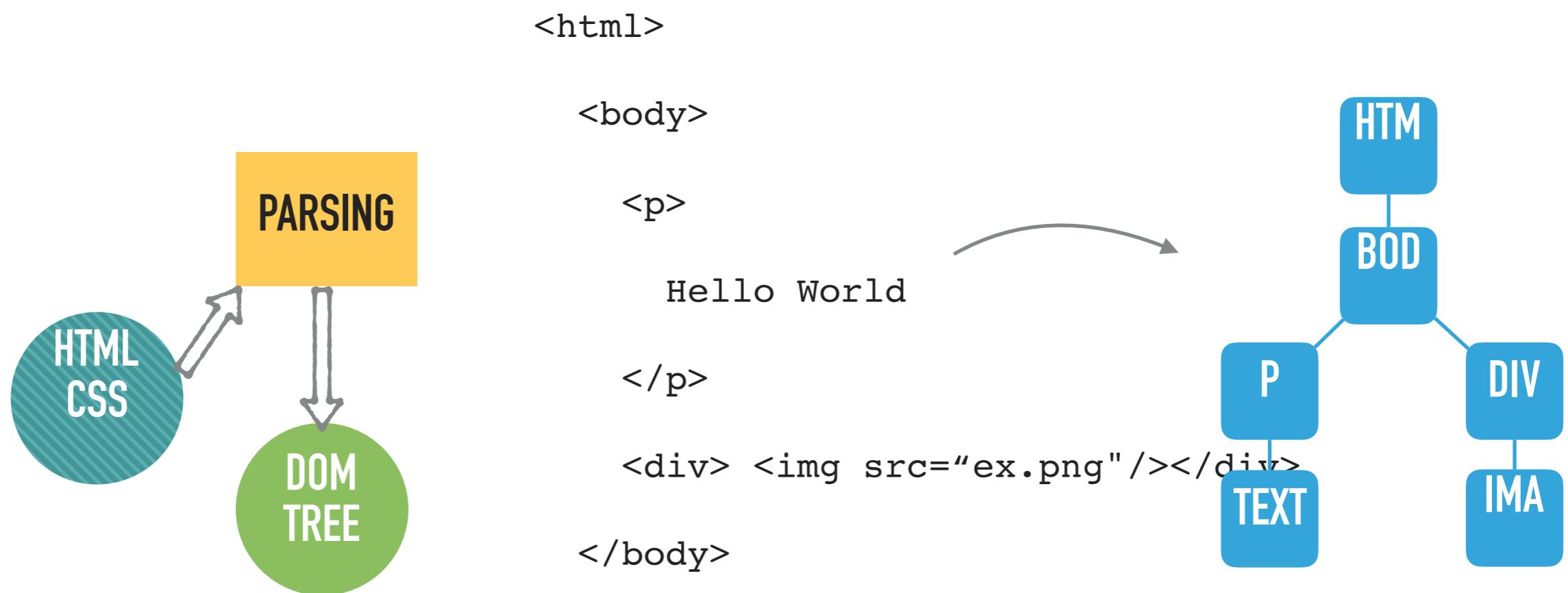
University of California, Irvine

[rzambre@uci.edu](mailto:rzambre@uci.edu) | [rohitzambre.com](http://rohitzambre.com)

QUESTIONS?

# BACKUP SLIDES

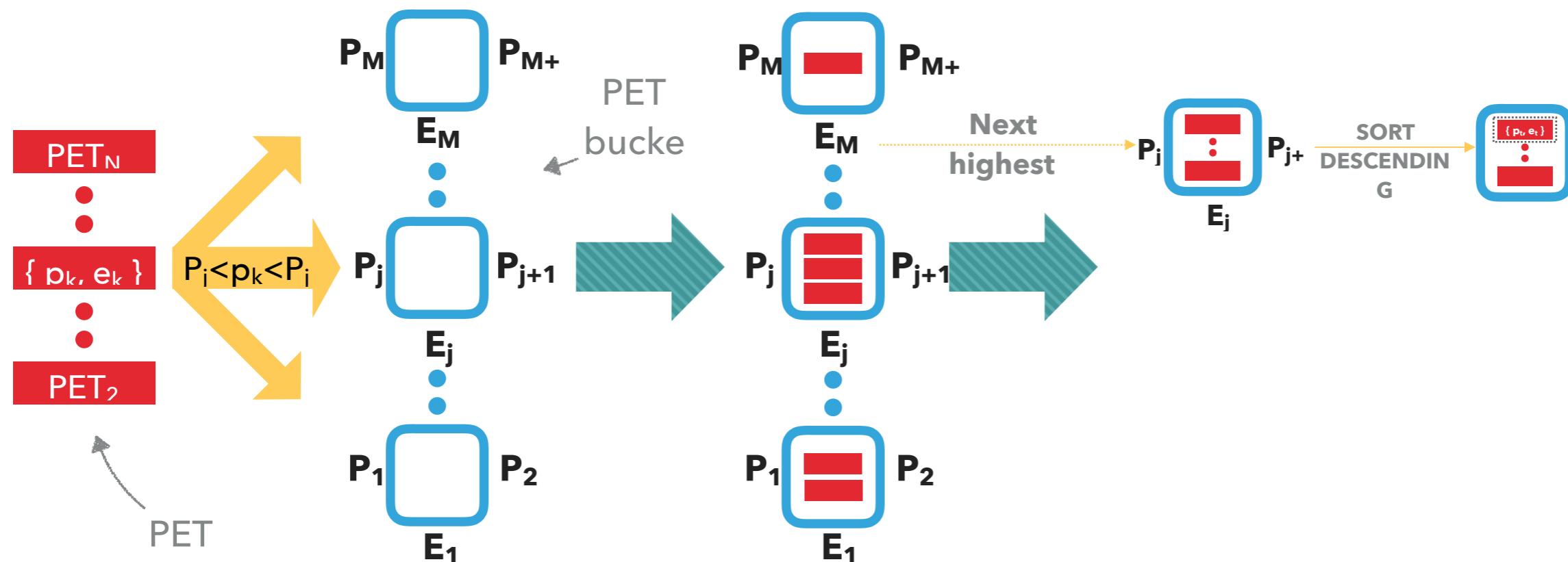
# PARALLEL BROWSER INTERNALS



- ▶ Parallel parsing by Zhao et al. [34]

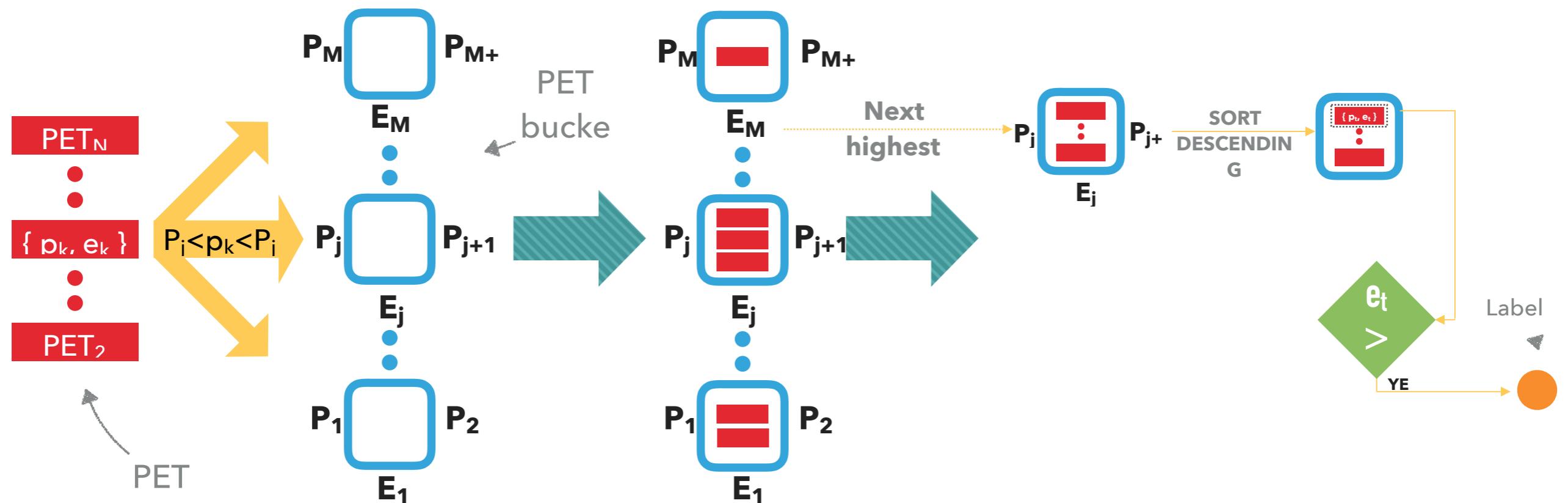
## PARALLEL PERFORMANCE-ENERGY PREDICTIVE MODELING OF BROWSERS

# AUTOMATED LABELING



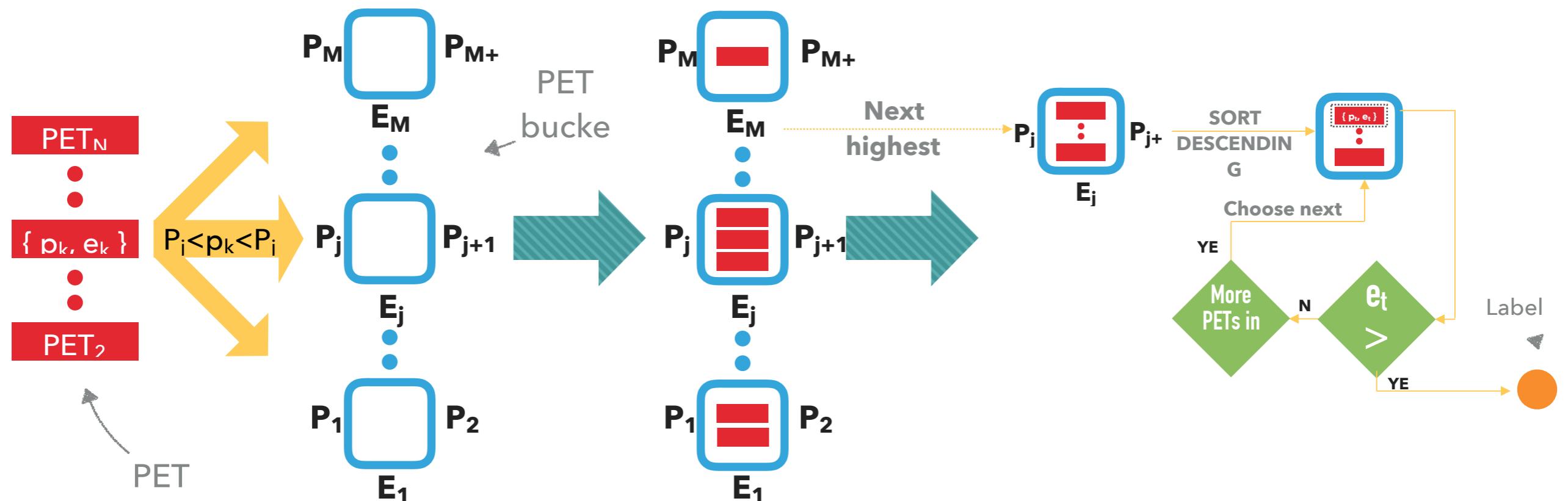
## PARALLEL PERFORMANCE-ENERGY PREDICTIVE MODELING OF BROWSERS

# AUTOMATED LABELING



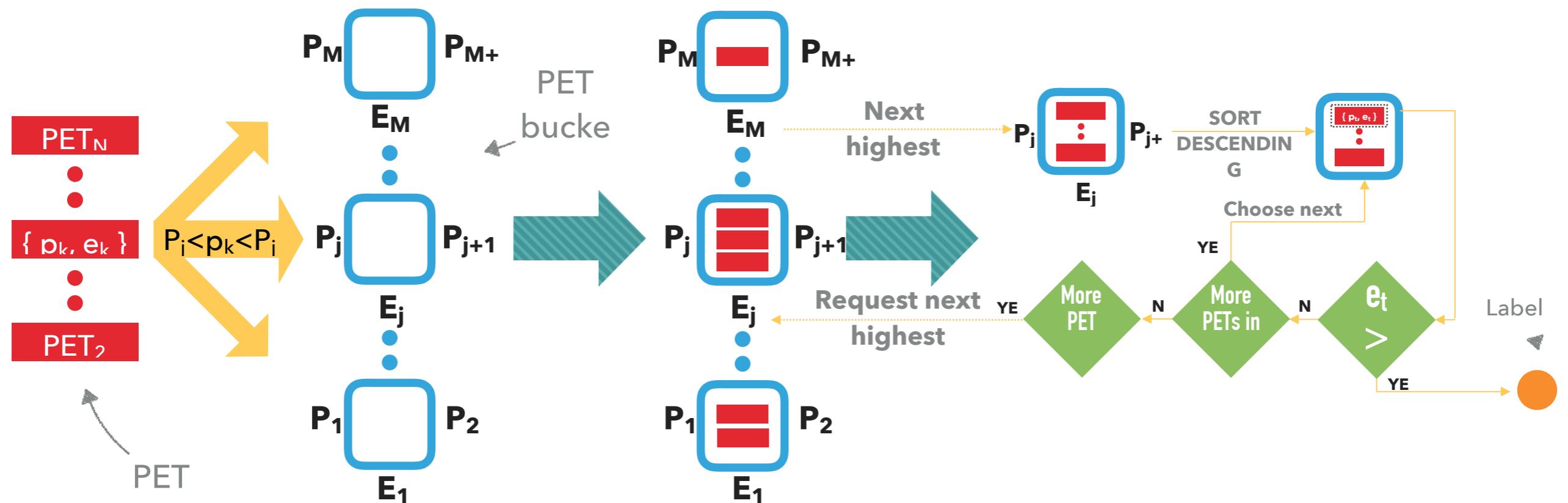
## PARALLEL PERFORMANCE-ENERGY PREDICTIVE MODELING OF BROWSERS

# AUTOMATED LABELING



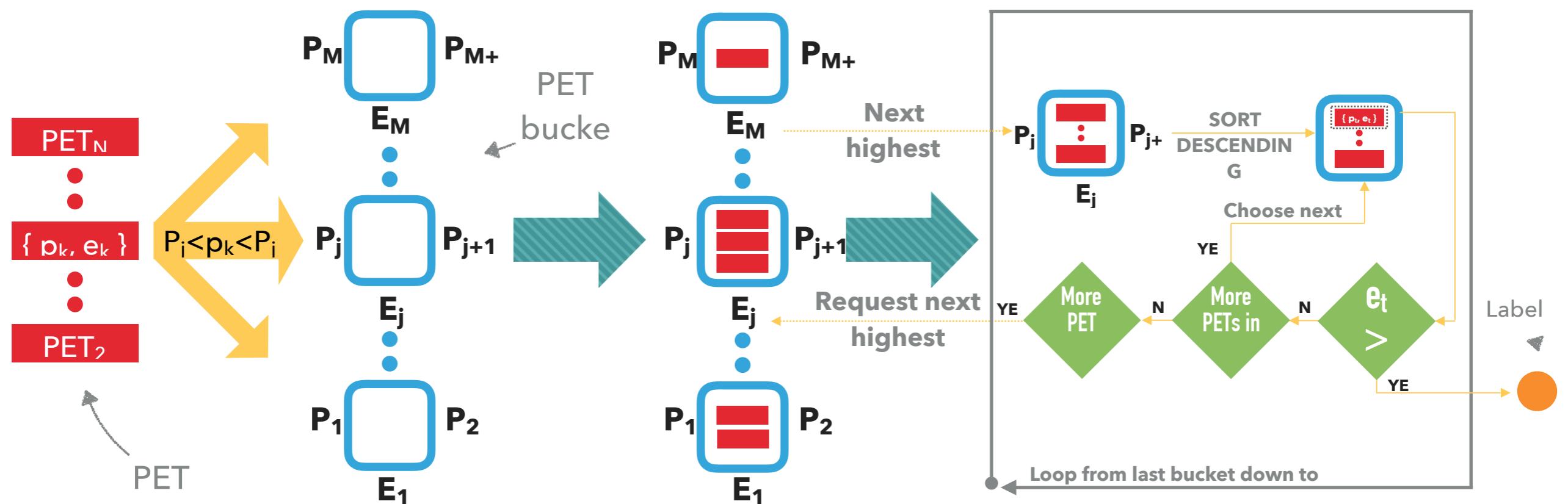
## PARALLEL PERFORMANCE-ENERGY PREDICTIVE MODELING OF BROWSERS

# AUTOMATED LABELING



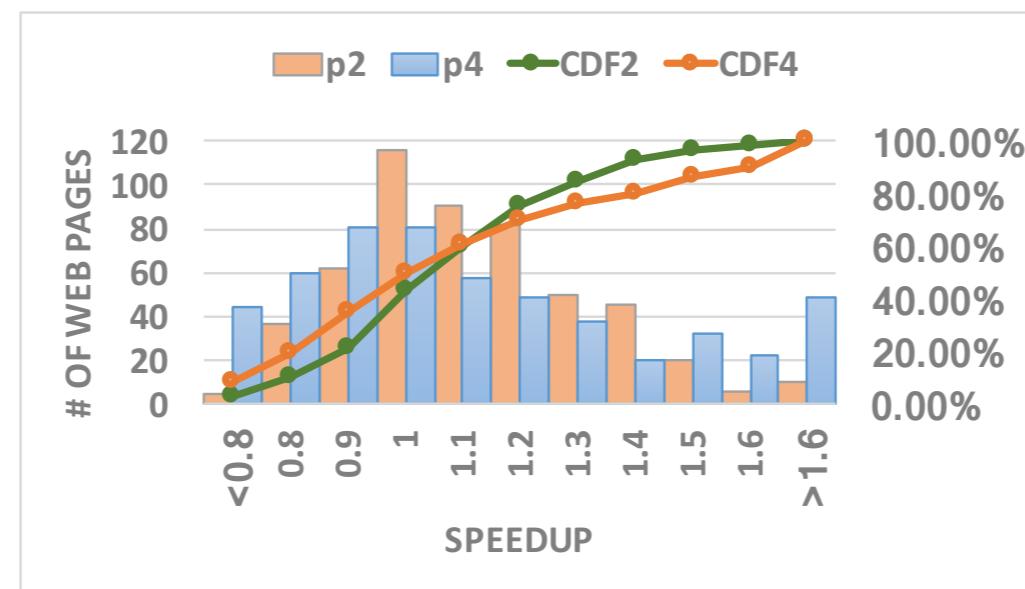
## PARALLEL PERFORMANCE-ENERGY PREDICTIVE MODELING OF BROWSERS

# AUTOMATED LABELING



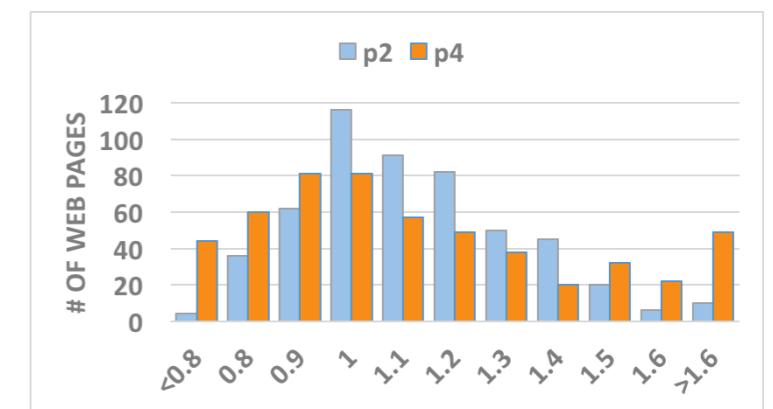
# LABELING & LEARNING

- ▶ Two PET buckets



# LABELING & LEARNING

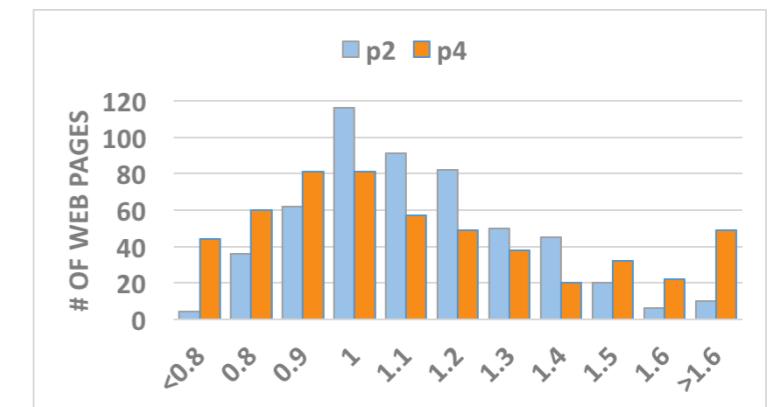
- ▶ Two PET buckets



- ▶ Labels → **1**: 59.3%; **2**: 9.3%; **4**: 31.4%

# LABELING & LEARNING

- ▶ Two PET buckets



- ▶ Labels → **1**: 59.3%; **2**: 9.3%; **4**: 31.4%
- ▶ Off-the-shelf supervised learning methods