Toward Semantic Foundations for Program Editors

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SNAPL 2017

Semanticists usually study complete programs

```
fun summary_stats(m : matrix<float>) =
  { mean   = stats.mean(m, ColumnWise),
    std    = stats.std(m, ColumnWise),
    median = stats.median(m, ColumnWise)
  }
```

Q: What about incomplete programs?

```
fun summary_stats(m : matrix<float>) =
  { mean   = stats.mean(m, ColumnWise),
    std    = stats.std(m,
    median =
```

syntactically malformed program text

Syntactic error recovery heuristics

```
fun summary_stats(m : matrix<float>) =
  { mean   = stats.mean(m, ColumnWise),
    std    = stats.std(m, ▢),
    median = ▢
  }
```

syntactically malformed program text → term with holes

[Kats et al., OOPSLA 2009]

Syntactic structure editors

```
fun summary_stats(m : matrix<float>) =
  { mean   = stats.mean(m, ColumnWise),
    std    = stats.std(m, ▢),
    median = ▢
  }
```

~~syntactically malformed program text →~~ term with holes

[Teitelbaum and Reps, Comm. ACM 1981; many others]

Q: How to **reason statically** about terms with holes?

```
fun summary_stats(m : matrix<float>) =
  { mean   = stats.mean(m, ColumnWise),
    std    = stats.std(m, ▢),
    median = ▢
  }
```

Q: How to **reason statically** about terms with holes?

```
fun summary_stats(m : matrix<float>) =
  { mean   = stats.mean(m, ColumnWise),
    std    = stats.std(m, ▢),
    median = ▢
  }
```

What **type** of expression is expected here?

Q: How to **reason statically** about terms with holes?

What **type** is synthesized for the function as a whole?

```
fun summary_stats(m : matrix<float>) =
  { mean   = stats.mean(m, ColumnWise),
    std    = stats.std(m, ▢),
    median = ▢
  }
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  { mean   = stats.mean(m, ColumnWise),
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```

What **type** of expression is expected here?

A: A **static semantics** for terms with holes.

Q: How to **reason statically** about terms with holes?

What **type** is synthesized for the function as a whole?

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fun summary_stats(m : matrix<float>) =
  { mean   = stats.mean(m, ColumnWise),
    std    = stats.std(m, ▢),
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  }
```

What **type** of expression is expected here?

A: A **static semantics** for terms with holes.

[Omar et al., POPL 2017]

Q: How to **reason statically** about terms with holes?

What **type** is synthesized for the function as a whole?

```
matrix<float> →
  { mean   : vec<float>,
    std    : vec<float>,
    median : ▢ }
```

```
fun summary_stats(m : matrix<float>) =
  { mean   = stats.mean(m, ColumnWise),
    std    = stats.std(m, ▢),
    median = ▢
  }
```

What **type** of expression is expected here?

A: A **static semantics** for terms with holes.

[Omar et al., POPL 2017]

Q: How to **reason statically** about terms with holes?

What **type** is synthesized for the function as a whole?

```
matrix<float> →
  { mean   : vec<float>,
    std    : vec<float>,
    median : ▢ }
```

```
fun summary_stats(m : matrix<float>) =
  { mean   = stats.mean(m, ColumnWise),
    std    = stats.std(m, ▢),
    median = ▢
  }
```

What **type** of expression is expected here?

```
(RowWise | ColumnWise)
```

A: A **static semantics** for terms with holes.

[Omar et al., POPL 2017]

Q: How to **reason statically** about terms with type inconsistencies?

What **type** is synthesized for the function as a whole?

```
fun summary_stats(m : matrix<float>) =
 { mean   = stats.mean(m, ColumnWise),
   std    = stats.std(m, “oops”),
   median = ▢
 }
```

A: A **static semantics** for terms with holes.

[Omar et al., POPL 2017]

Q: How to **reason statically** about terms with type inconsistencies?

What **type** is synthesized for the function as a whole?

```
fun summary_stats(m : matrix<float>) =
  { mean   = stats.mean(m, ColumnWise),
    std    = stats.std(m, “oops”),
    median = ▢
  }
```

Reify type inconsistencies as non-empty holes!

A: A **static semantics** for terms with holes.

[Omar et al., POPL 2017]

Q: How to **reason statically** about terms with type inconsistencies?

What **type** is synthesized for the function as a whole?

```
matrix<float> →
  { mean   : vec<float>,
    std    : vec<float>,
    median : ▢ }
```

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fun summary_stats(m : matrix<float>) =
  { mean   = stats.mean(m, ColumnWise),
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    median = ▢
  }
```

Reify type inconsistencies as non-empty holes!

A: A **static semantics** for terms with holes.

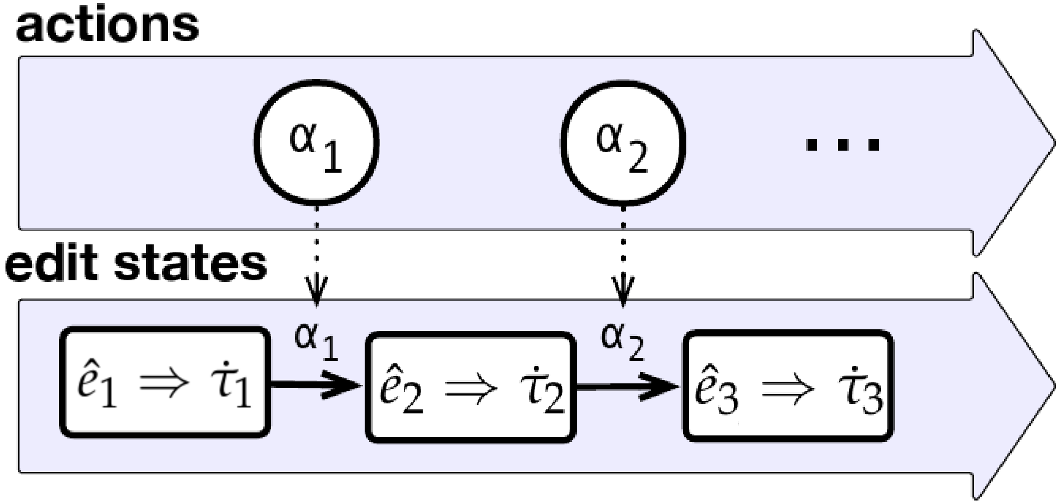
[Omar et al., POPL 2017]

A **static semantics** for lambda terms with holes

$$
\begin{array}{llll}
\mathsf{HTyp} & \dot{\tau} & ::= & (\dot{\tau} \to \dot{\tau}) \mid \mathtt{num} \mid \llparenthesis\rrparenthesis \\
\mathsf{HExp} & \dot{e} & ::= & x \mid (\lambda x.\dot{e}) \mid \dot{e}(\dot{e}) \mid \underline{n} \mid (\dot{e} + \dot{e}) \mid \dot{e} : \dot{\tau} \mid \llparenthesis\rrparenthesis \mid \llparenthesis\dot{e}\rrparenthesis
\end{array}
$$

[Omar et al., POPL 2017]

Hazelnut: A typed edit action semantics


actions
α_1
α_2
...
edit states
α_1
α_2
$\hat{e}_1 \Rightarrow \dot{\tau}_1$
$\hat{e}_2 \Rightarrow \dot{\tau}_2$
$\hat{e}_3 \Rightarrow \dot{\tau}_3$

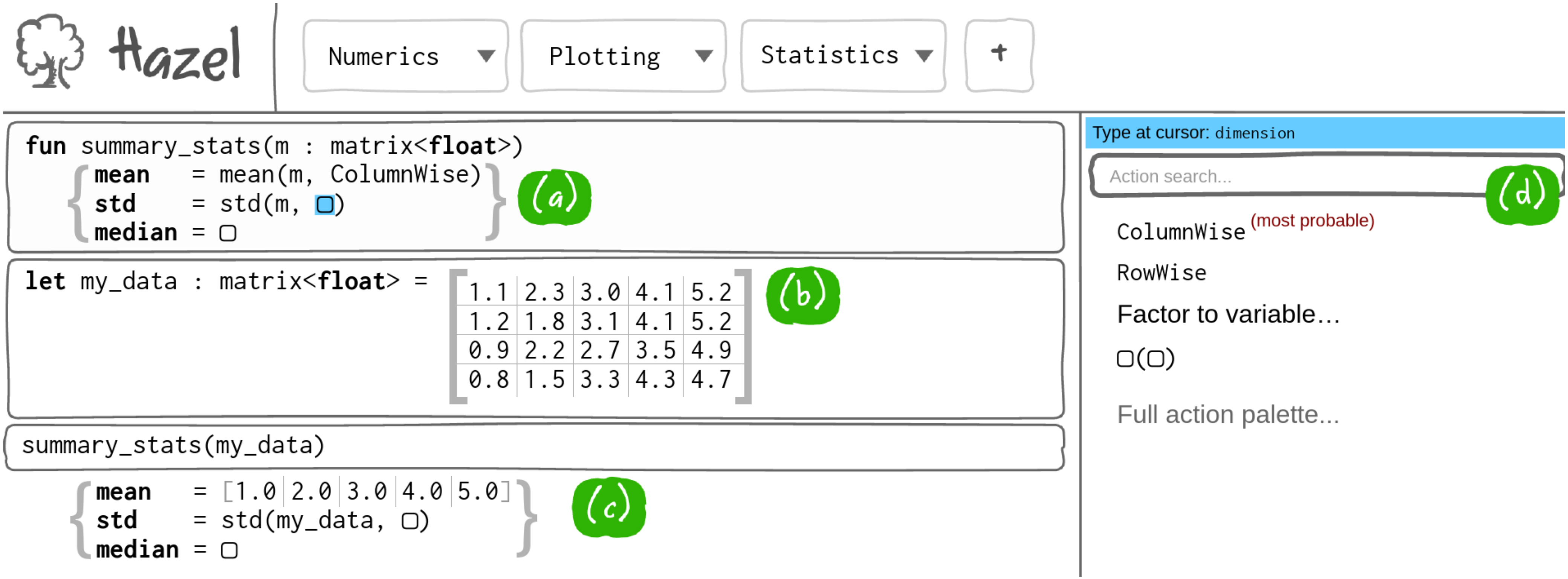
[Omar et al., POPL 2017]

Demo

See http://hazelgrove.org/hazel/hazel.html

[Omar et al., POPL 2017]

From Hazelnut to Hazel



```
fun summary_stats(m : matrix<float>)
    { mean   = mean(m, ColumnWise)
      std    = std(m, ▢)
      median = ▢ }
```

```
let my_data : matrix<float> =
```

1.1	2.3	3.0	4.1	5.2
1.2	1.8	3.1	4.1	5.2
0.9	2.2	2.7	3.5	4.9
0.8	1.5	3.3	4.3	4.7

```
summary_stats(my_data)
```

```
{ mean   = [1.0 2.0 3.0 4.0 5.0]
  std    = std(my_data, ▢)
  median = ▢ }
```

Type at cursor: `dimension`

Action search...

ColumnWise (most probable)

RowWise

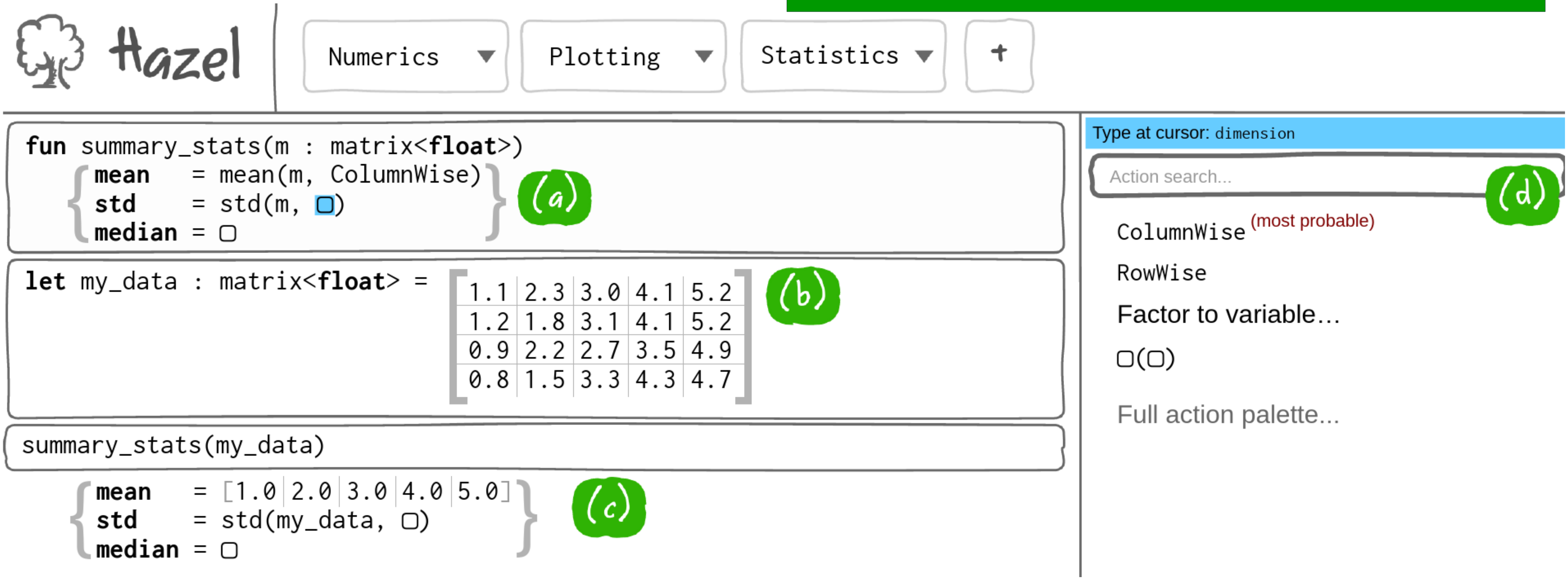
Factor to variable…

▢(▢)

Full action palette...

From Hazelnut to **Hazel**

Web-based UI. Libraries are Git repos w/URLs.



```
fun summary_stats(m : matrix<float>)
    { mean   = mean(m, ColumnWise) }
    { std    = std(m, □)           }
    { median = □                   }
```

```
let my_data : matrix<float> =
```

1.1	2.3	3.0	4.1	5.2
1.2	1.8	3.1	4.1	5.2
0.9	2.2	2.7	3.5	4.9
0.8	1.5	3.3	4.3	4.7

```
summary_stats(my_data)
```

```
{ mean   = [1.0 | 2.0 | 3.0 | 4.0 | 5.0] }
{ std    = std(my_data, □)               }
{ median = □                             }
```

Type at cursor: dimension

Action search...

ColumnWise (most probable)

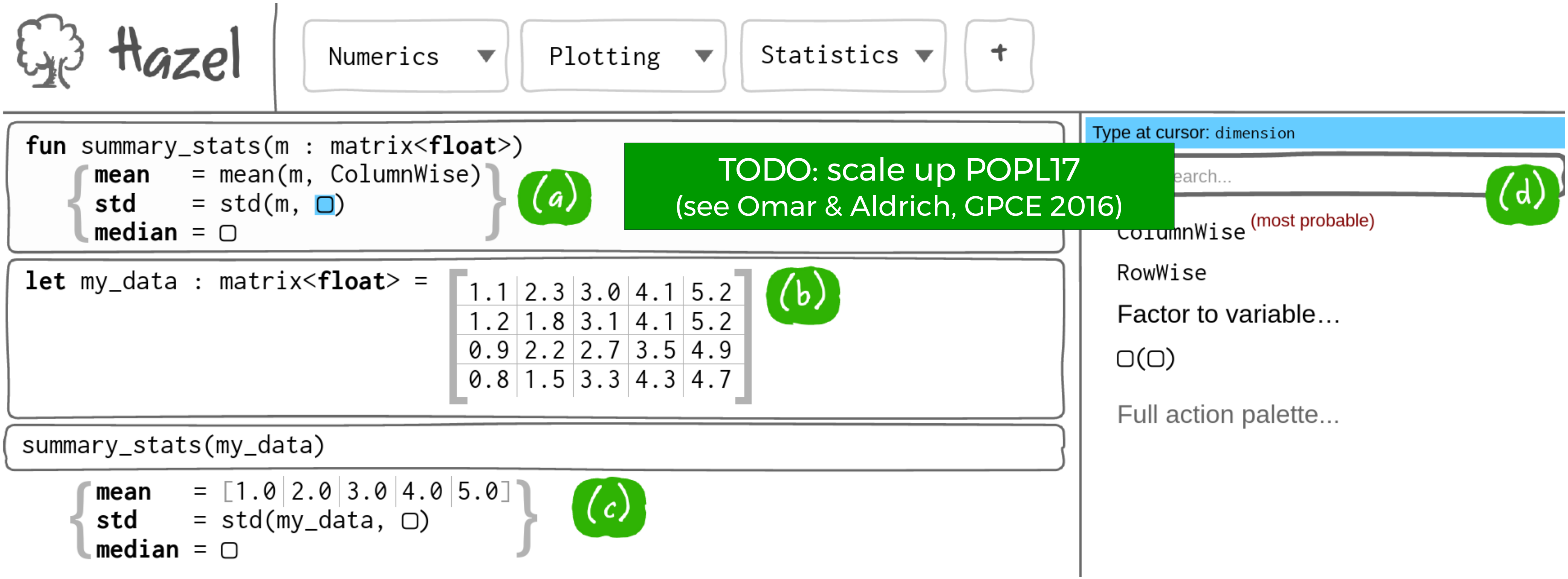
RowWise

Factor to variable…

□(□)

Full action palette...

From Hazelnut to **Hazel**



```
fun summary_stats(m : matrix<float>)
    { mean   = mean(m, ColumnWise) }
    { std    = std(m, □)           }
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```
summary_stats(my_data)
```

```
    { mean   = [1.0 2.0 3.0 4.0 5.0] }
    { std    = std(my_data, □)        }
    { median = □                      }
```

Type at cursor: dimension

Search...

ColumnWise (most probable)

RowWise

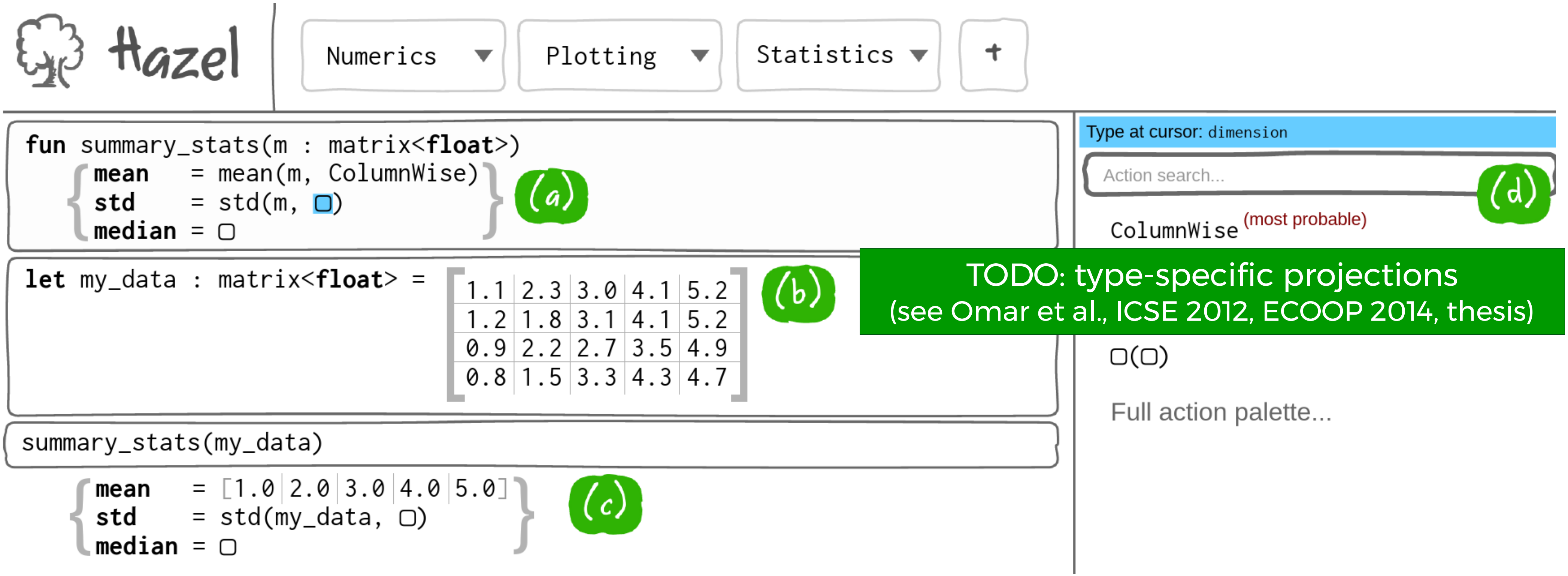
Factor to variable…

□(□)

Full action palette...

TODO: scale up POPL17
(see Omar & Aldrich, GPCE 2016)

From Hazelnut to Hazel



```
fun summary_stats(m : matrix<float>)
  { mean   = mean(m, ColumnWise) }
  { std    = std(m, □)           }
  { median = □                   }

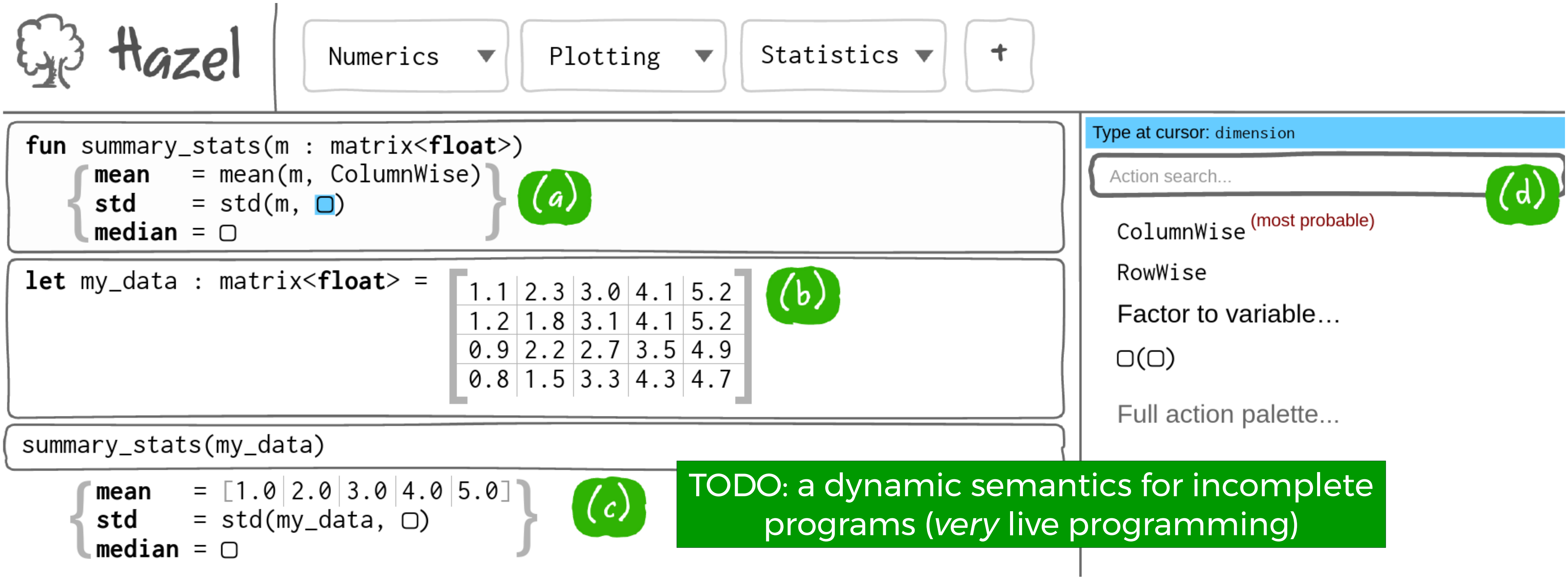
let my_data : matrix<float> = [ 1.1 | 2.3 | 3.0 | 4.1 | 5.2 ]
                              [ 1.2 | 1.8 | 3.1 | 4.1 | 5.2 ]
                              [ 0.9 | 2.2 | 2.7 | 3.5 | 4.9 ]
                              [ 0.8 | 1.5 | 3.3 | 4.3 | 4.7 ]

summary_stats(my_data)

  { mean   = [1.0 | 2.0 | 3.0 | 4.0 | 5.0] }
  { std    = std(my_data, □)               }
  { median = □                             }
```

TODO: type-specific projections
(see Omar et al., ICSE 2012, ECOOP 2014, thesis)

From Hazelnut to **Hazel**



```
fun summary_stats(m : matrix<float>)
    { mean   = mean(m, ColumnWise)
      std    = std(m, □)
      median = □ }
```

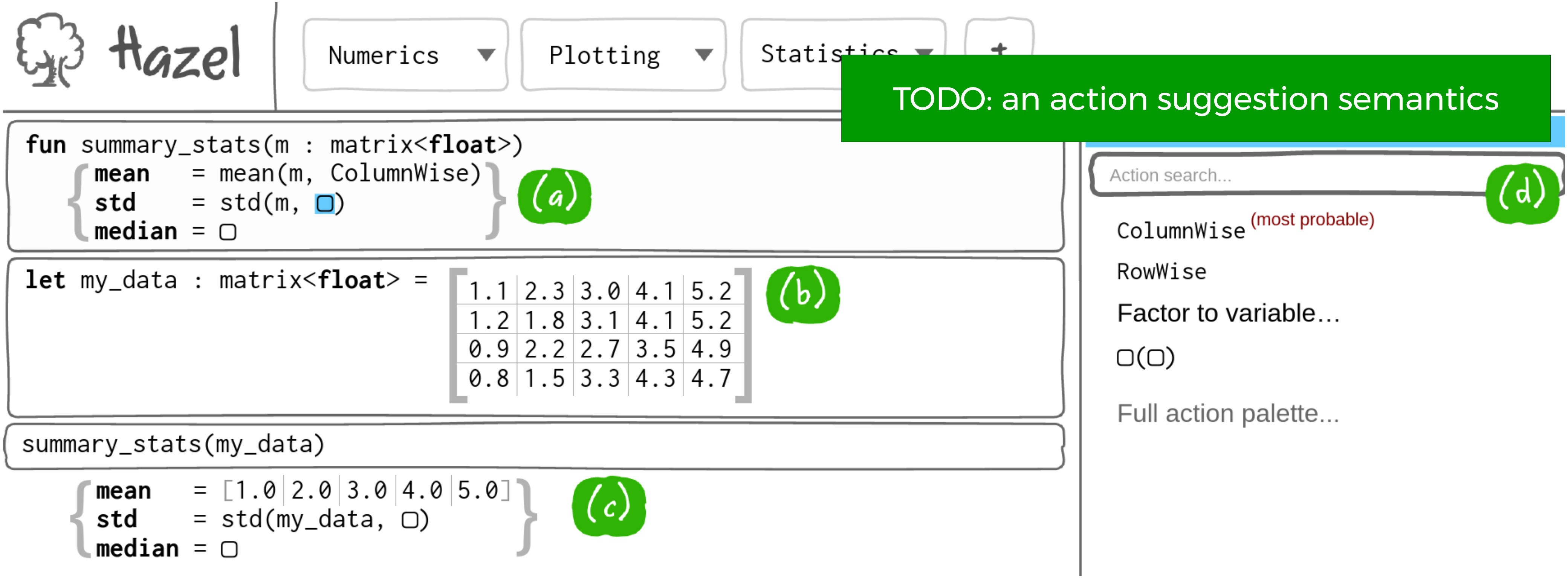
```
let my_data : matrix<float> =
    [ 1.1 | 2.3 | 3.0 | 4.1 | 5.2
      1.2 | 1.8 | 3.1 | 4.1 | 5.2
      0.9 | 2.2 | 2.7 | 3.5 | 4.9
      0.8 | 1.5 | 3.3 | 4.3 | 4.7 ]
```

```
summary_stats(my_data)
```

```
    { mean   = [1.0 | 2.0 | 3.0 | 4.0 | 5.0]
      std    = std(my_data, □)
      median = □ }
```

TODO: a dynamic semantics for incomplete programs (*very* live programming)

From Hazelnut to **Hazel**



TODO: an action suggestion semantics

```
fun summary_stats(m : matrix<float>)
    { mean   = mean(m, ColumnWise) }
    { std    = std(m, □)           }
    { median = □                   }
```

```
let my_data : matrix<float> =
```

1.1	2.3	3.0	4.1	5.2
1.2	1.8	3.1	4.1	5.2
0.9	2.2	2.7	3.5	4.9
0.8	1.5	3.3	4.3	4.7

```
summary_stats(my_data)
```

```
    { mean   = [1.0 | 2.0 | 3.0 | 4.0 | 5.0] }
    { std    = std(my_data, □)               }
    { median = □                             }
```

Action search...

ColumnWise (most probable)

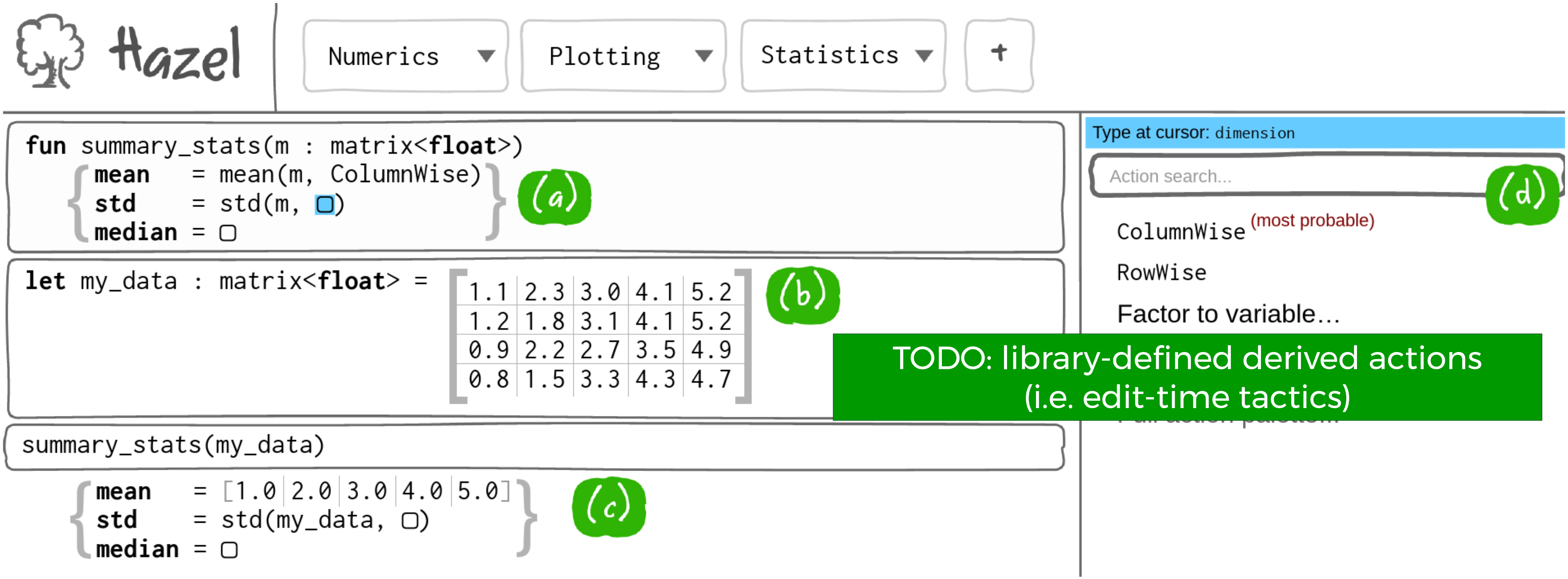
RowWise

Factor to variable…

□(□)

Full action palette...

From Hazelnut to **Hazel**



```
fun summary_stats(m : matrix<float>)
   { mean   = mean(m, ColumnWise) }
   { std    = std(m, ▢)         }
   { median = ▢                 }
```

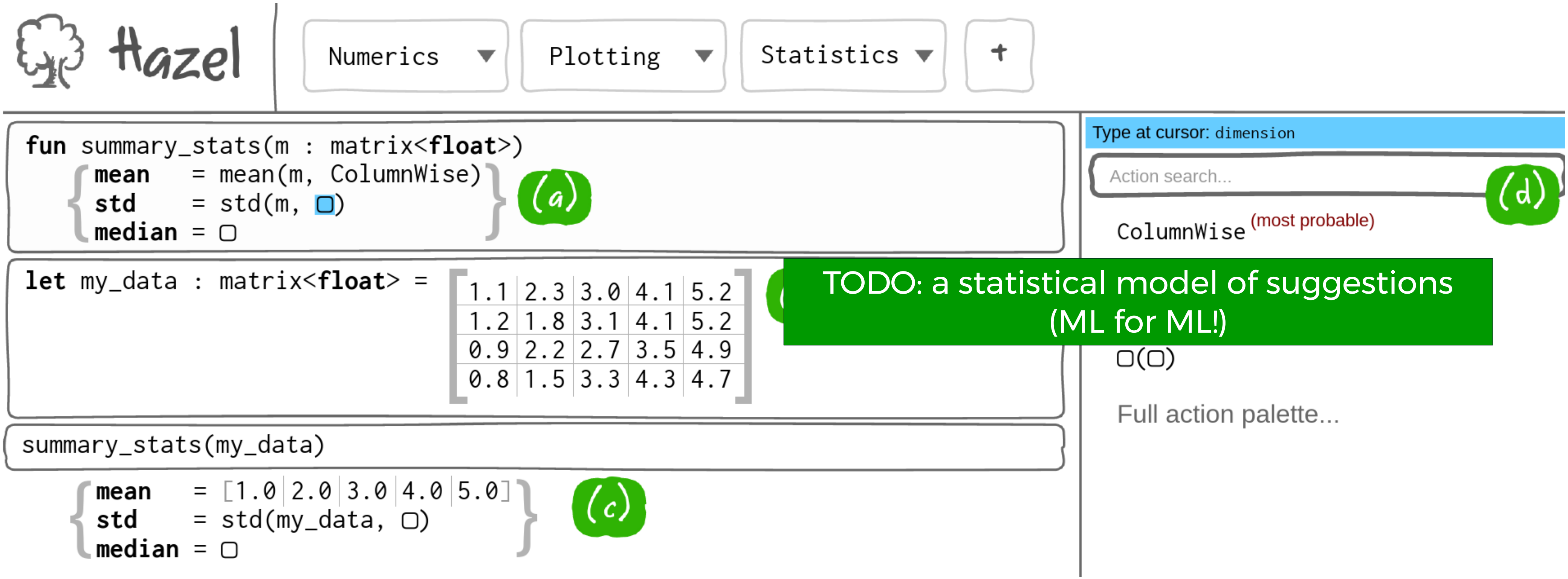
```
let my_data : matrix<float> = [ 1.1 | 2.3 | 3.0 | 4.1 | 5.2 ]
                              [ 1.2 | 1.8 | 3.1 | 4.1 | 5.2 ]
                              [ 0.9 | 2.2 | 2.7 | 3.5 | 4.9 ]
                              [ 0.8 | 1.5 | 3.3 | 4.3 | 4.7 ]
```

```
summary_stats(my_data)
```

```
   { mean   = [1.0 | 2.0 | 3.0 | 4.0 | 5.0] }
   { std    = std(my_data, ▢)              }
   { median = ▢                            }
```

TODO: library-defined derived actions
(i.e. edit-time tactics)

From Hazelnut to **Hazel**



```
fun summary_stats(m : matrix<float>)
    { mean   = mean(m, ColumnWise) }
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let my_data : matrix<float> = [ 1.1 | 2.3 | 3.0 | 4.1 | 5.2 ]
                              [ 1.2 | 1.8 | 3.1 | 4.1 | 5.2 ]
                              [ 0.9 | 2.2 | 2.7 | 3.5 | 4.9 ]
                              [ 0.8 | 1.5 | 3.3 | 4.3 | 4.7 ]

summary_stats(my_data)

    { mean   = [1.0 | 2.0 | 3.0 | 4.0 | 5.0] }
    { std    = std(my_data, □)               }
    { median = □                             }
```

Type at cursor: `dimension`

Action search...

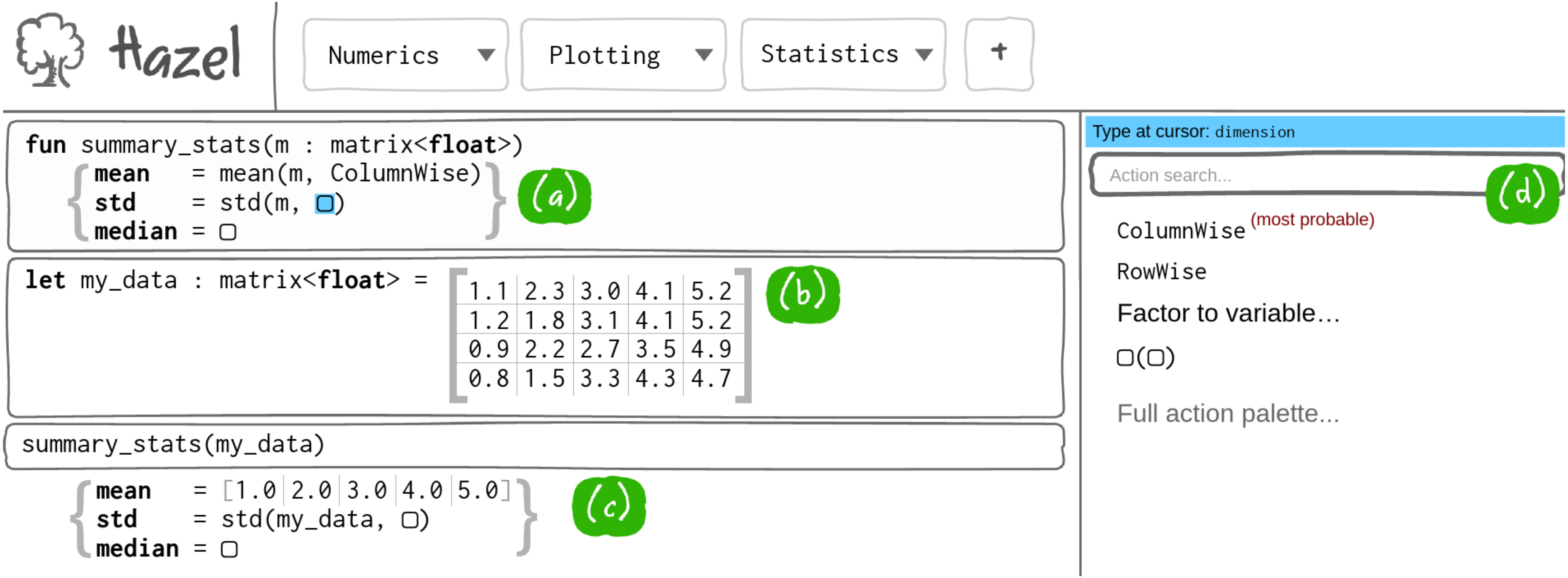
`ColumnWise` (most probable)

□(□)

Full action palette...

TODO: a statistical model of suggestions (ML for ML!)

From Hazelnut to Hazel



```
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let my_data : matrix<float> =
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```
summary_stats(my_data)

  { mean   = [1.0 2.0 3.0 4.0 5.0] }
  { std    = std(my_data, □)       }
  { median = □                     }
```

Type at cursor: dimension

Action search...

ColumnWise (most probable)

RowWise

Factor to variable…

□(□)

Full action palette...

A real opportunity to apply foundational type theory and modern PL techniques to deliver a **best-in-class programming experience**.