Application of UrbanSim Cloud-Based Land Use Forecasting Model Calibrated by Machine Learning & Automatic Differentiation

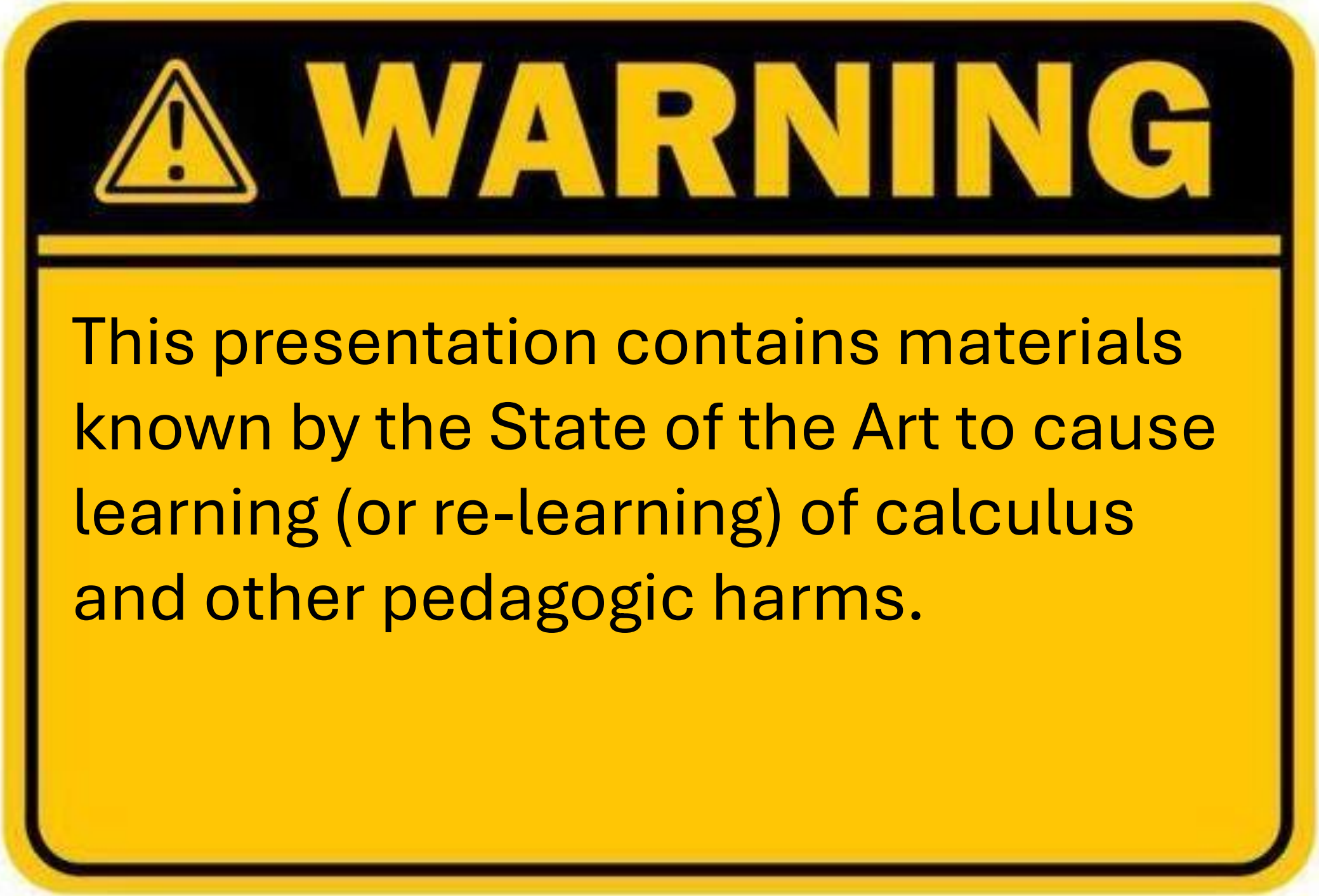
Early Results from the Portland-Vancouver-Hillsboro OR-WA Metropolitan Area

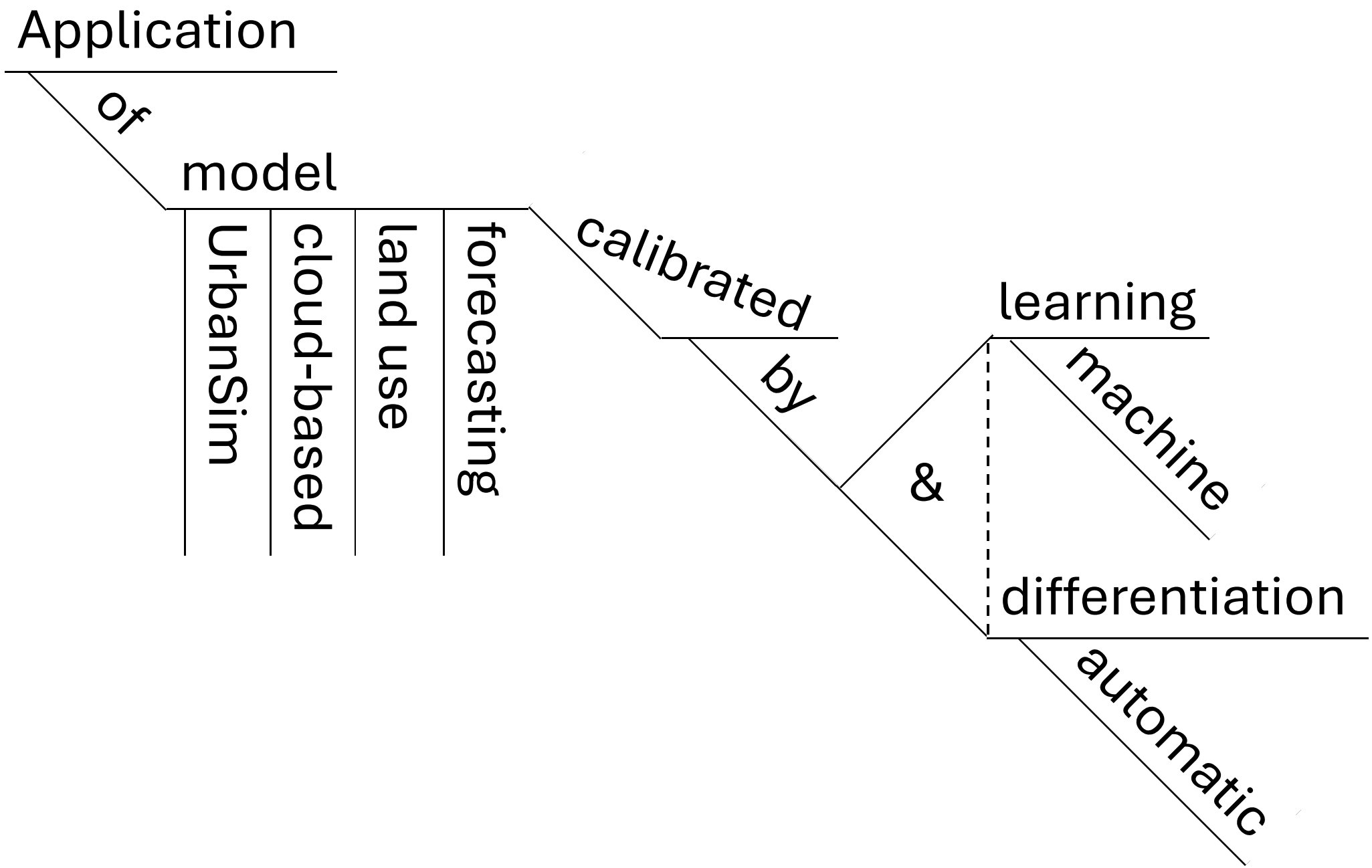
Jeffrey Hood – Senior Researcher & Modeler

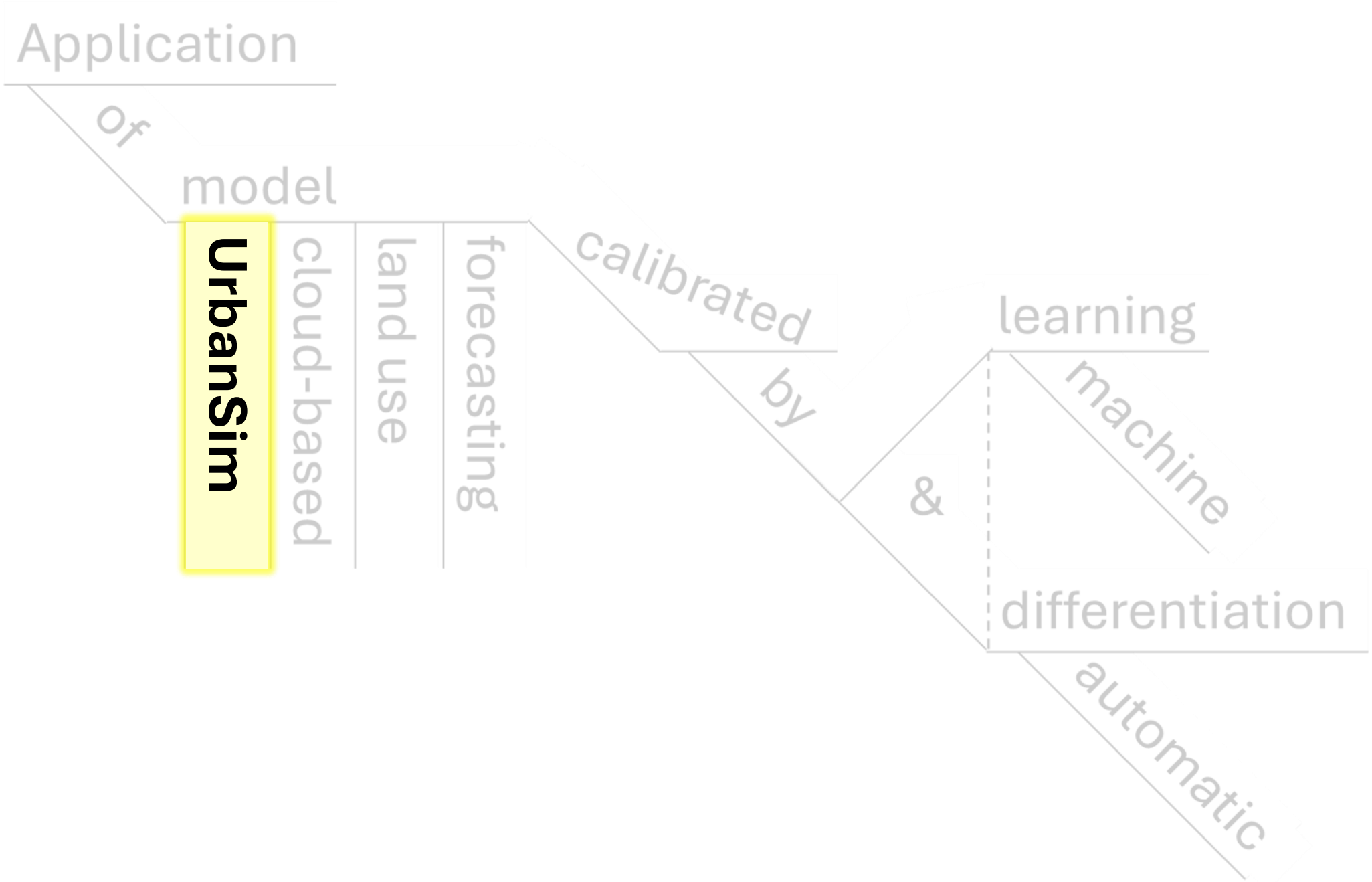
September 17th

2025 Modeling Mobility Conference – Minneapolis, Minnesota

Metro


WARNING
This presentation contains materials known by the State of the Art to cause learning (or re-learning) of calculus and other pedagogic harms.


Application
of
model
UrbanSim
cloud-based
land use
forecasting
calibrated
by
learning
machine
&
differentiation
automatic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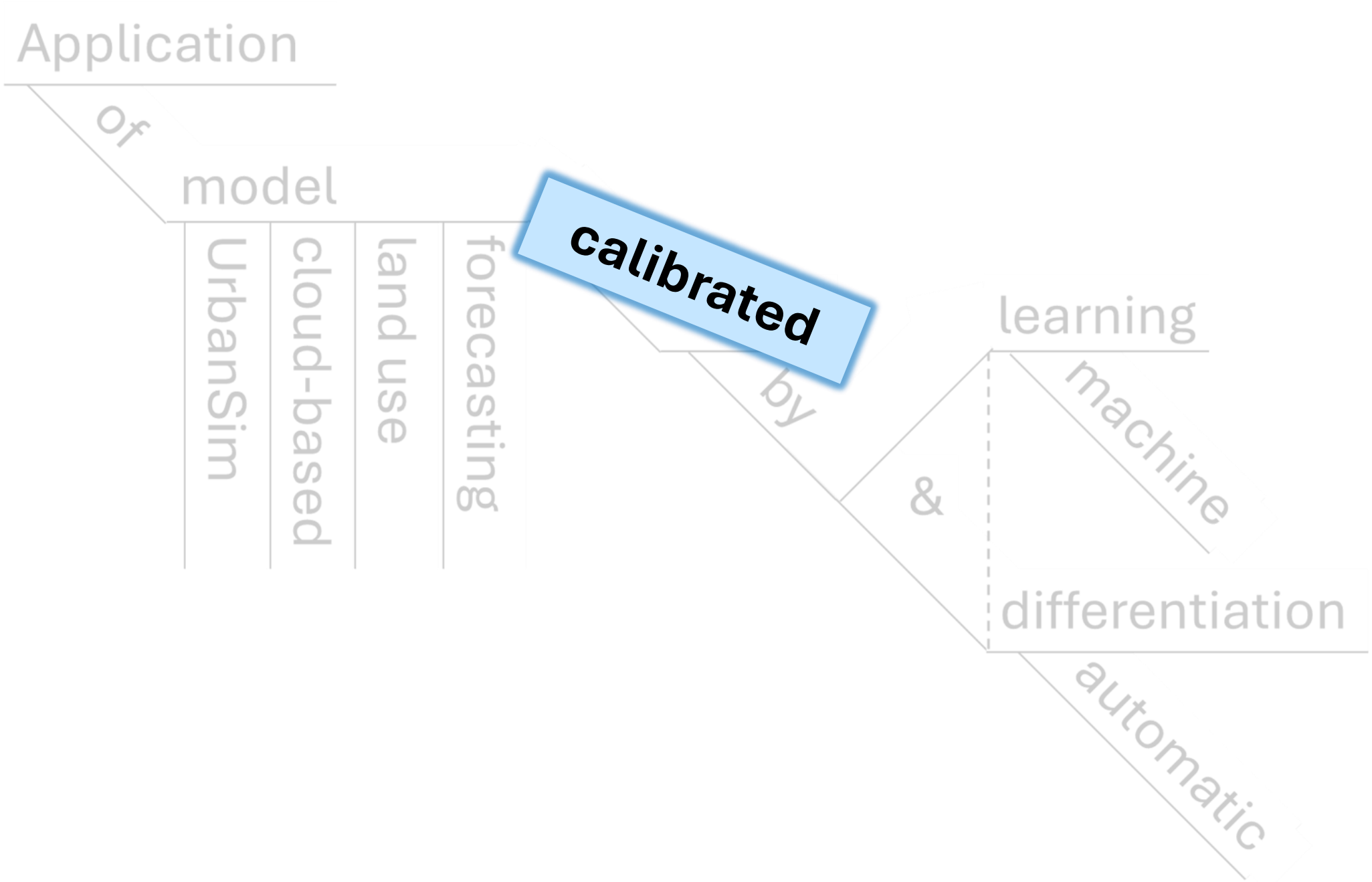
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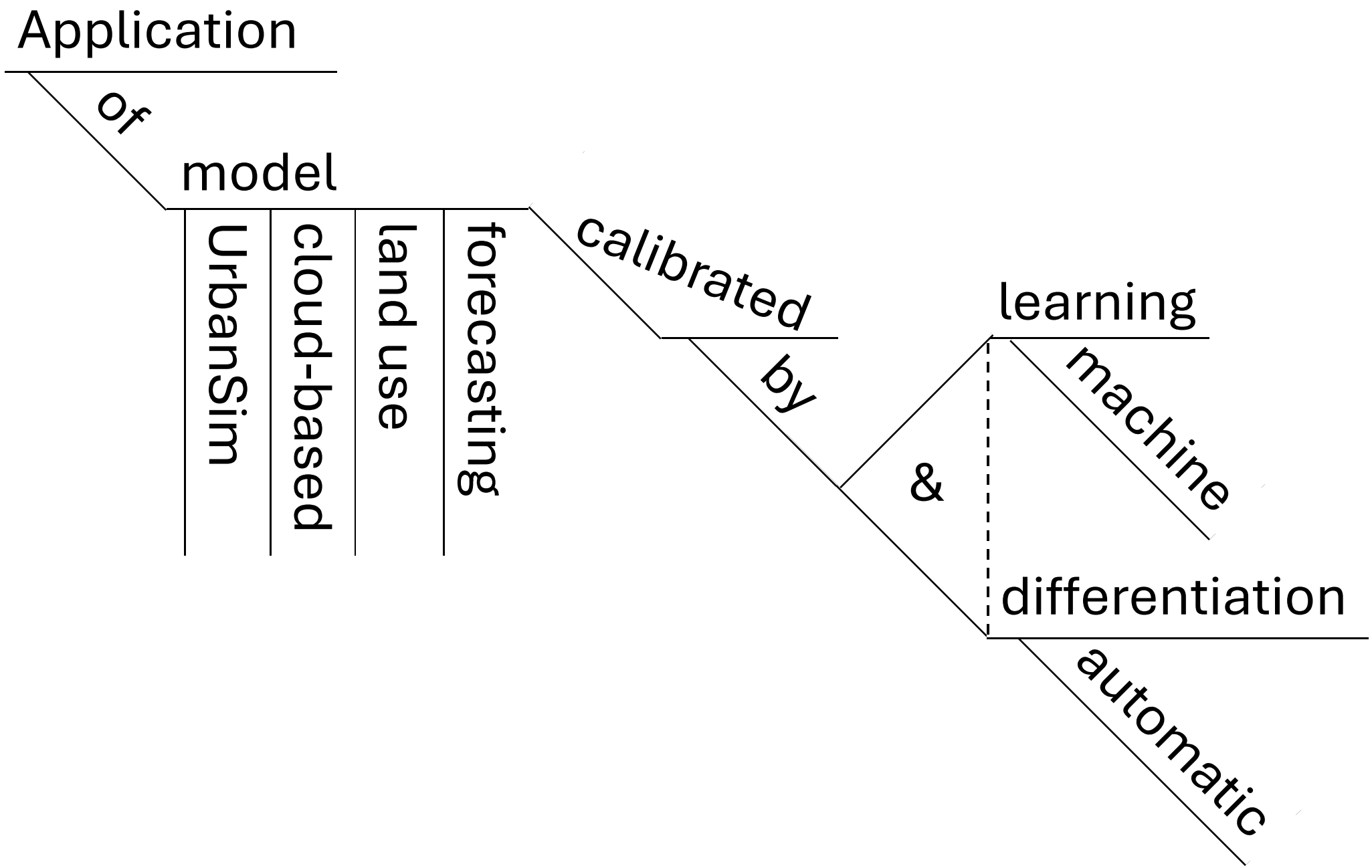
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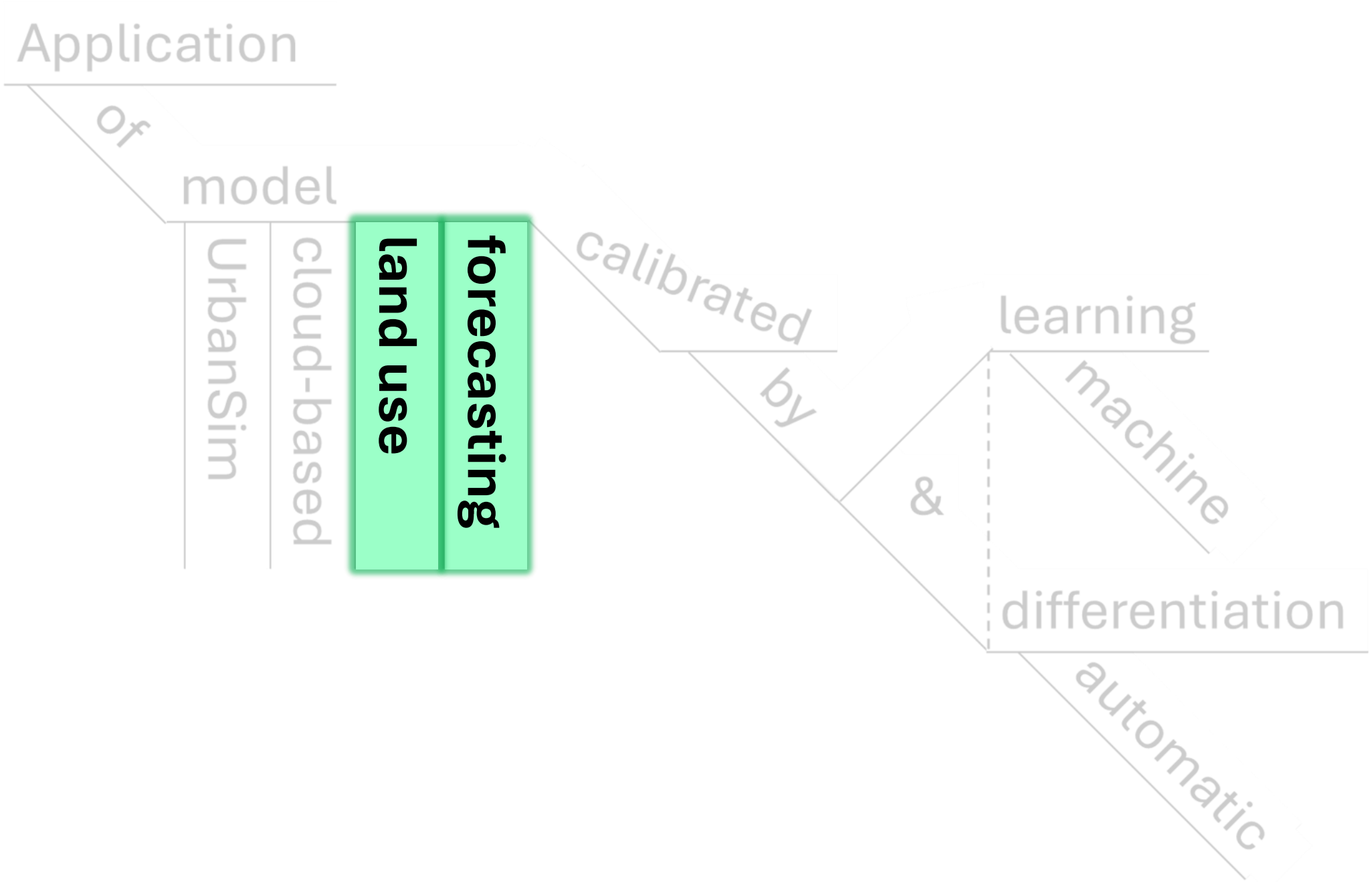
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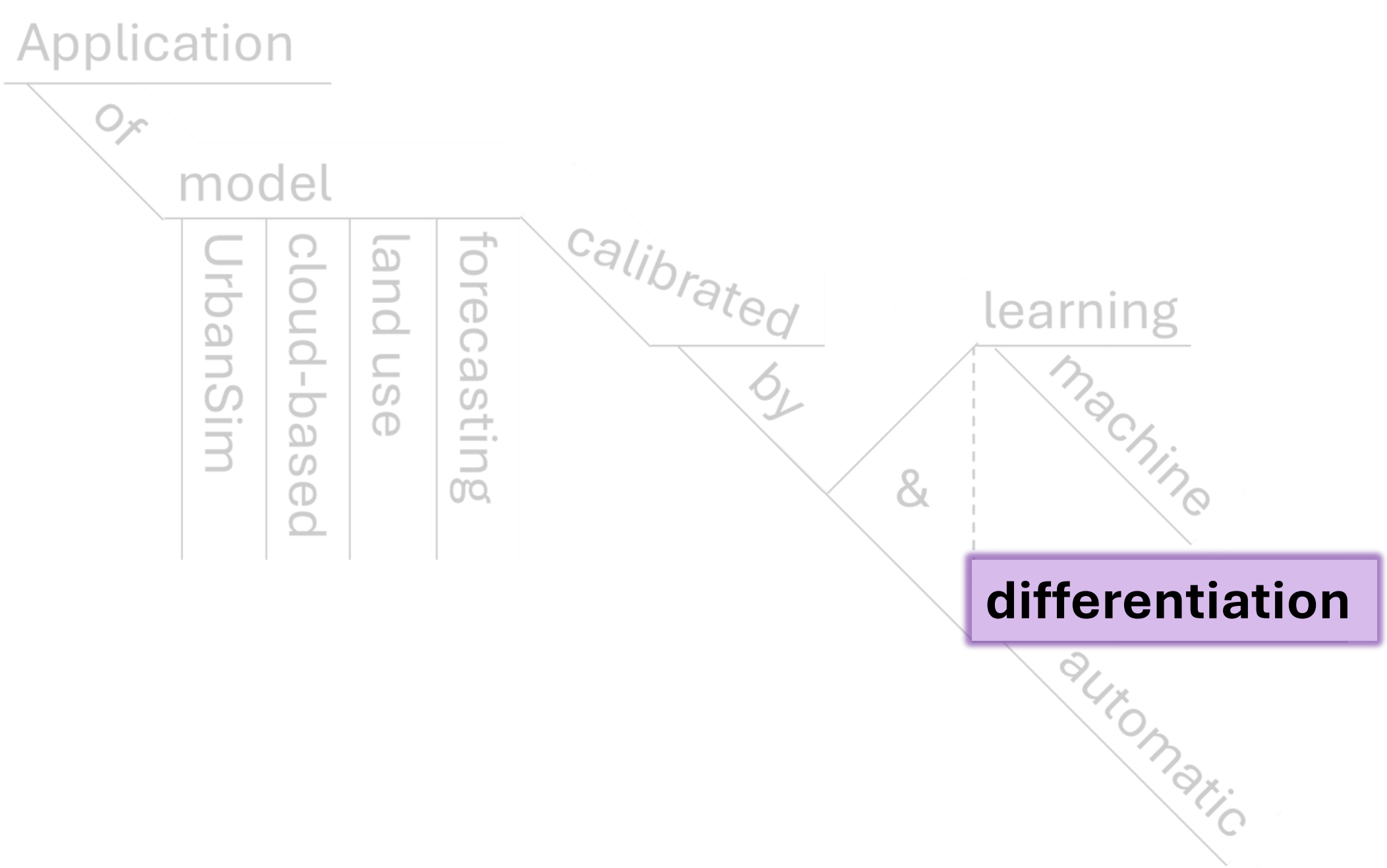
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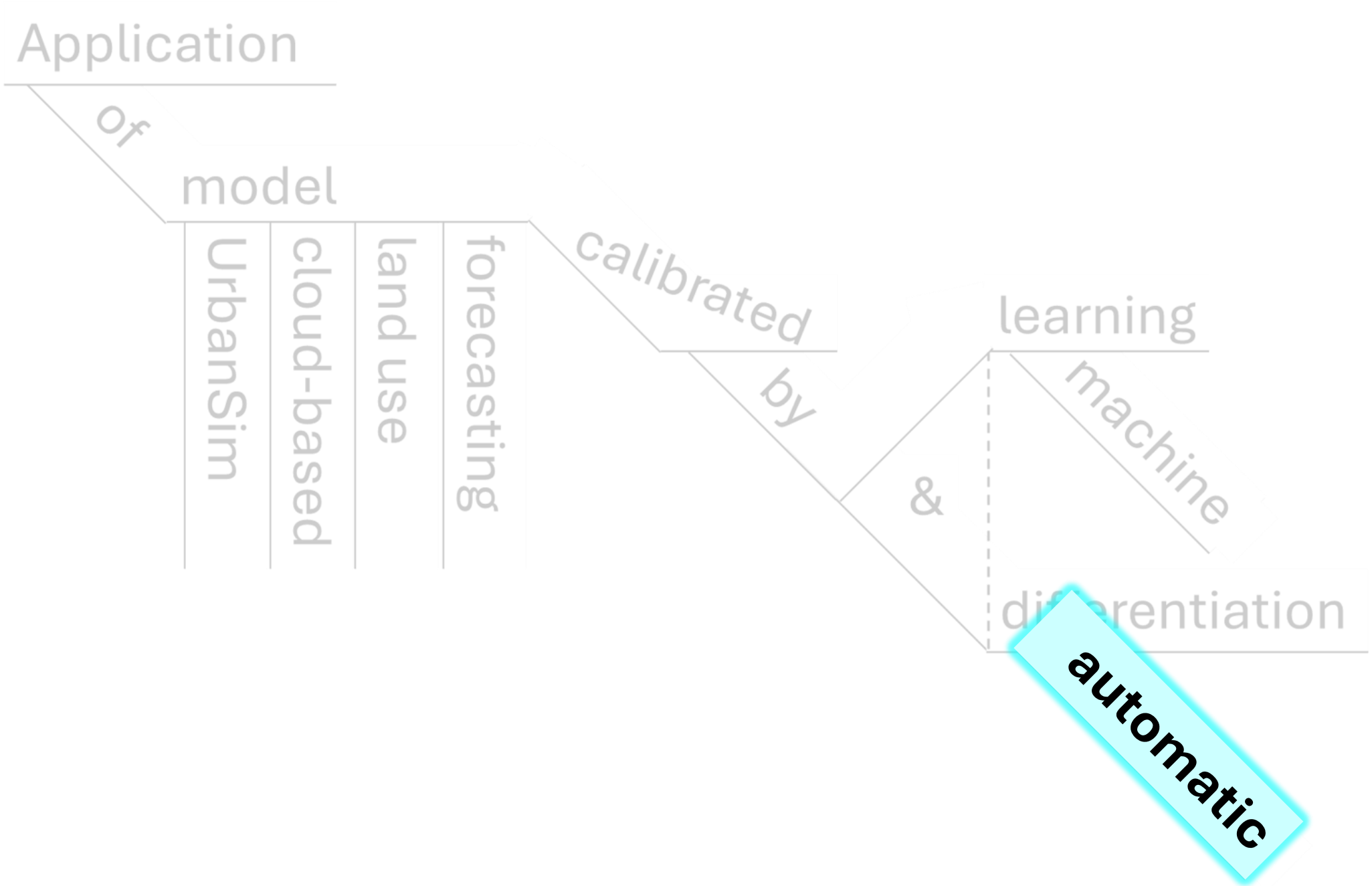
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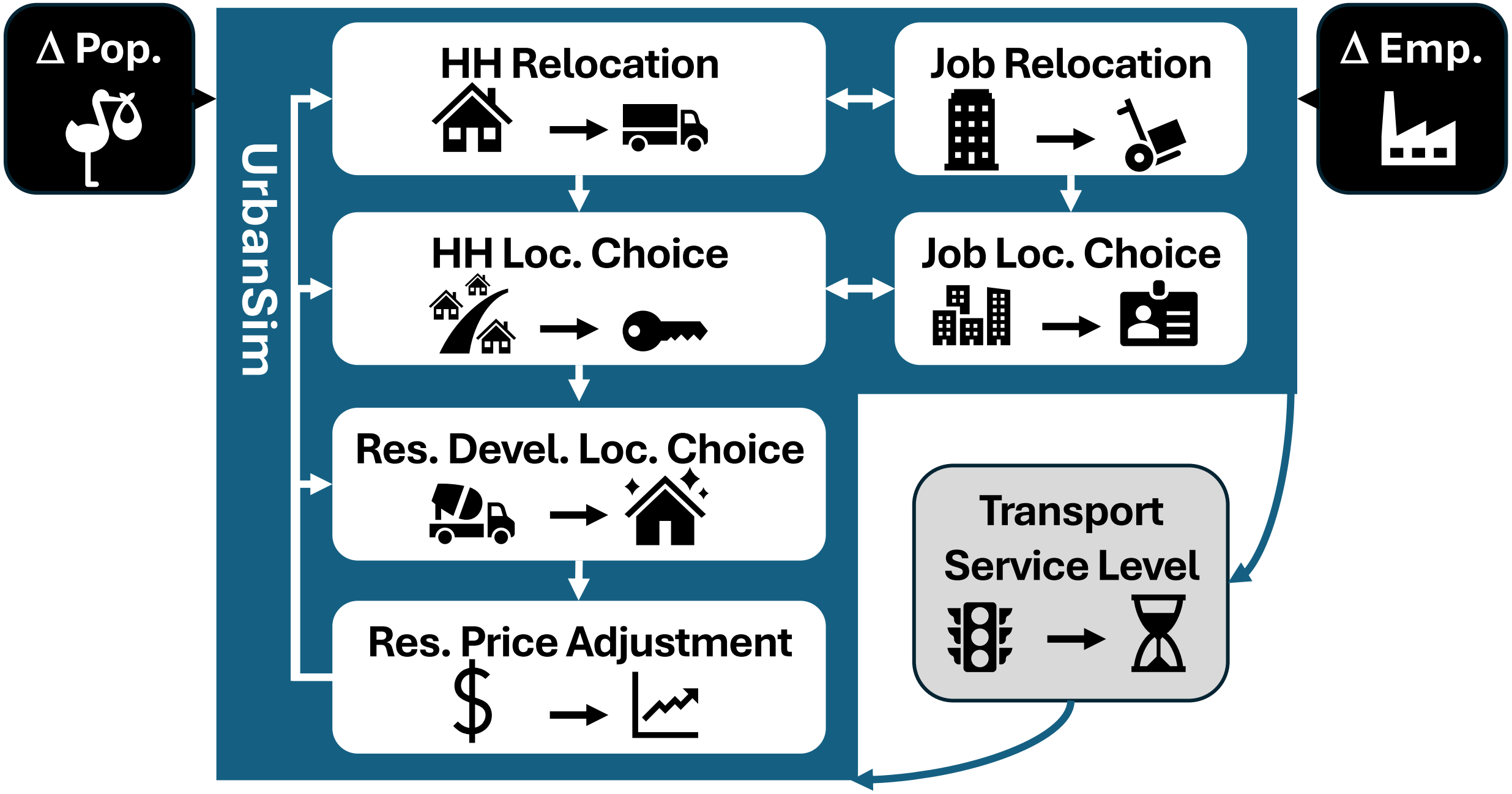
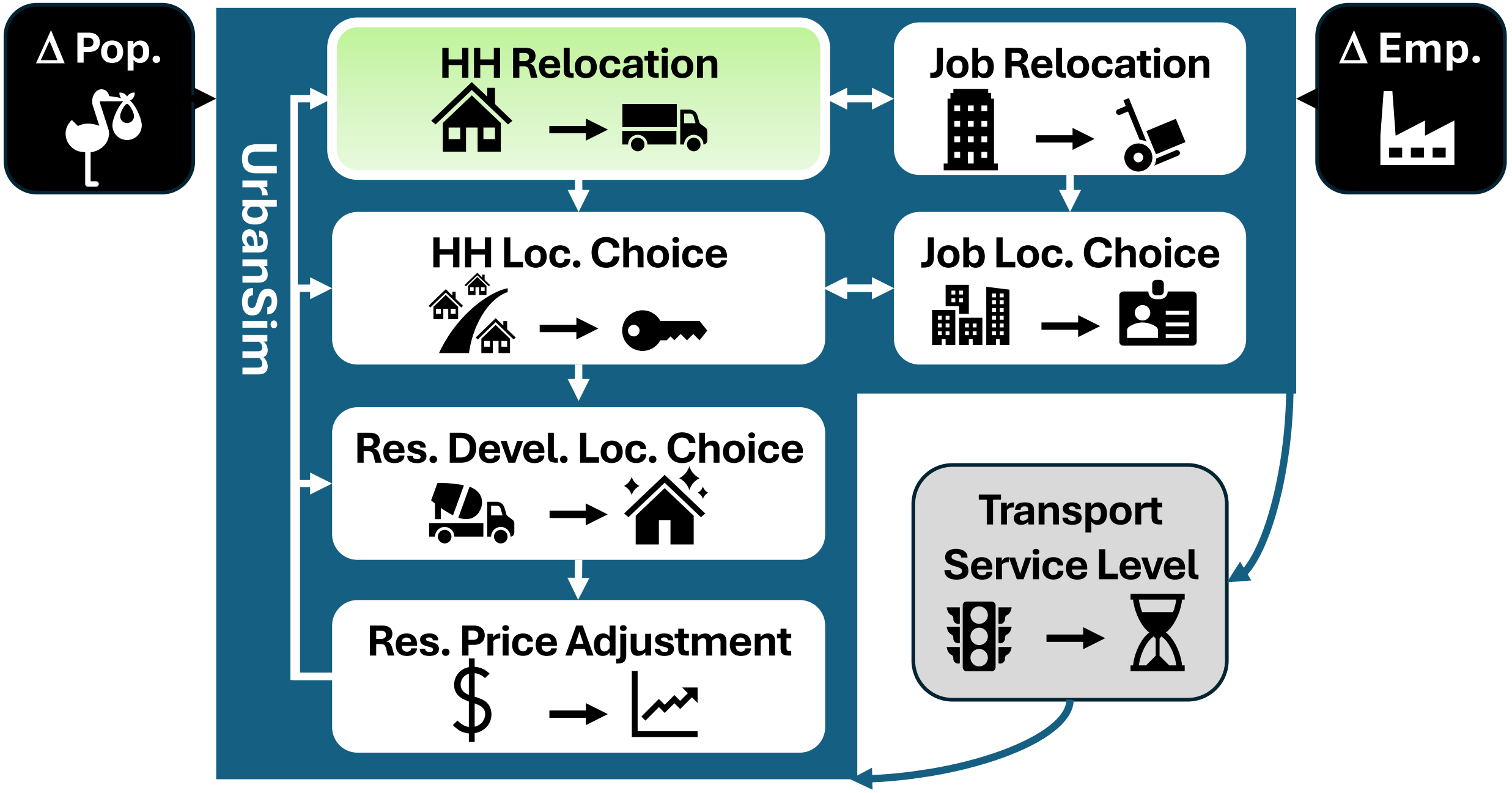

Δ Pop.
Δ Emp.
UrbanSim
HH Relocation
Job Relocation
HH Loc. Choice
Job Loc. Choice
Res. Devel. Loc. Choice
Res. Price Adjustment
Transport
Service Level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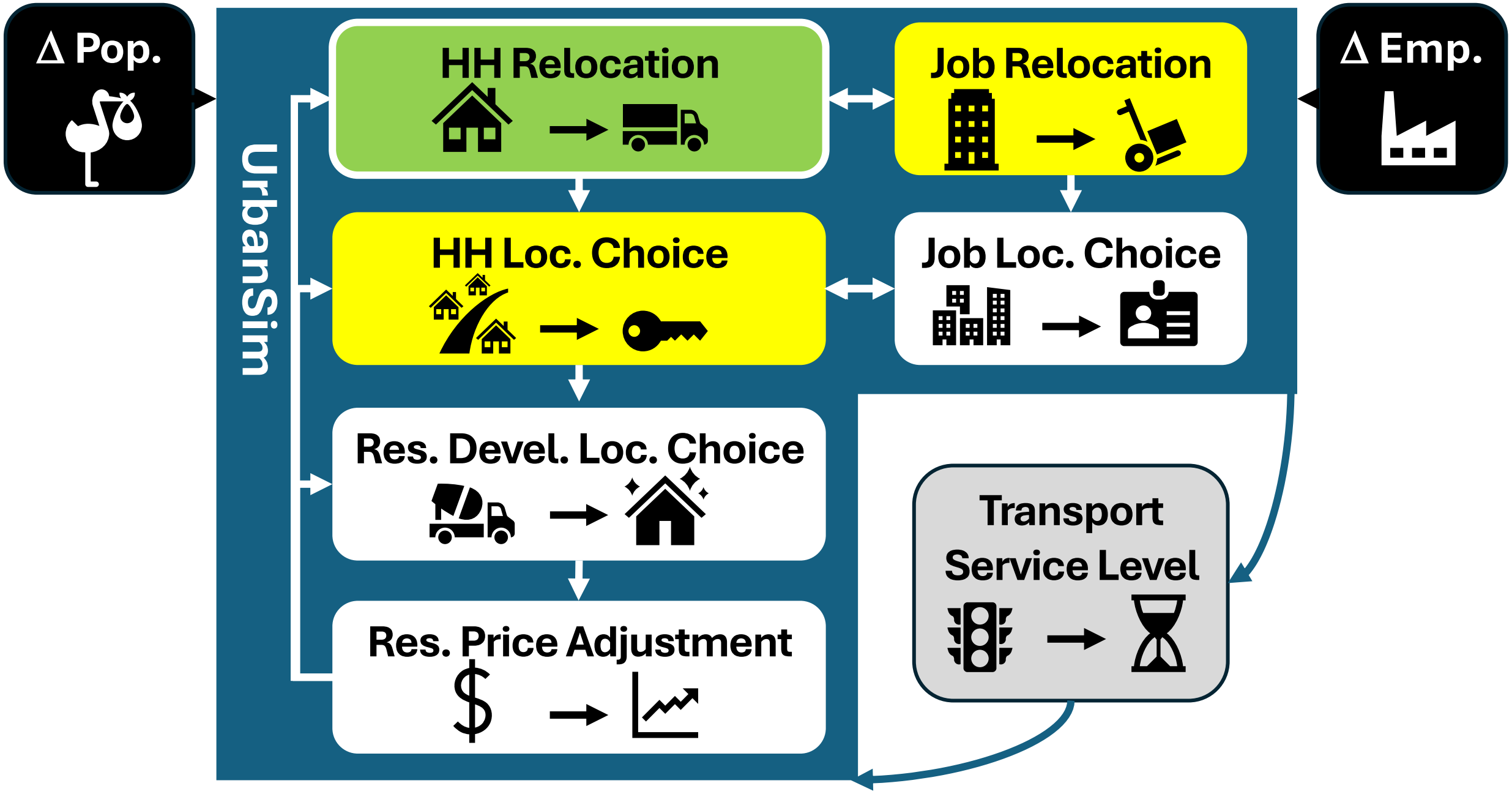
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HH Relocation
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HH Loc. Choice
Job Loc. Choice
Res. Devel. Loc. Choice
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Removed from web version due to uncertain copyright:

John Howard plugging holes in dyke wall with his fingers and toes, Howard under pressure to reduce rising unemployment figures

Published in the *Canberra Times* on 12 September 1997

By Australian political cartoonist Geoff Pryor

Available at National Library of Australia:

https://catalogue.nla.gov.au/catalog/4728563

Illustrative Analogue: Best Fit Line

Point	x coord.	y coord.
A	1	1
B	2	3

Equation form: $y = mx + b$

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Best fit $\rightarrow$ minimize the sum of squared deviations

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Point	x coord.	y coord.
A	1	1
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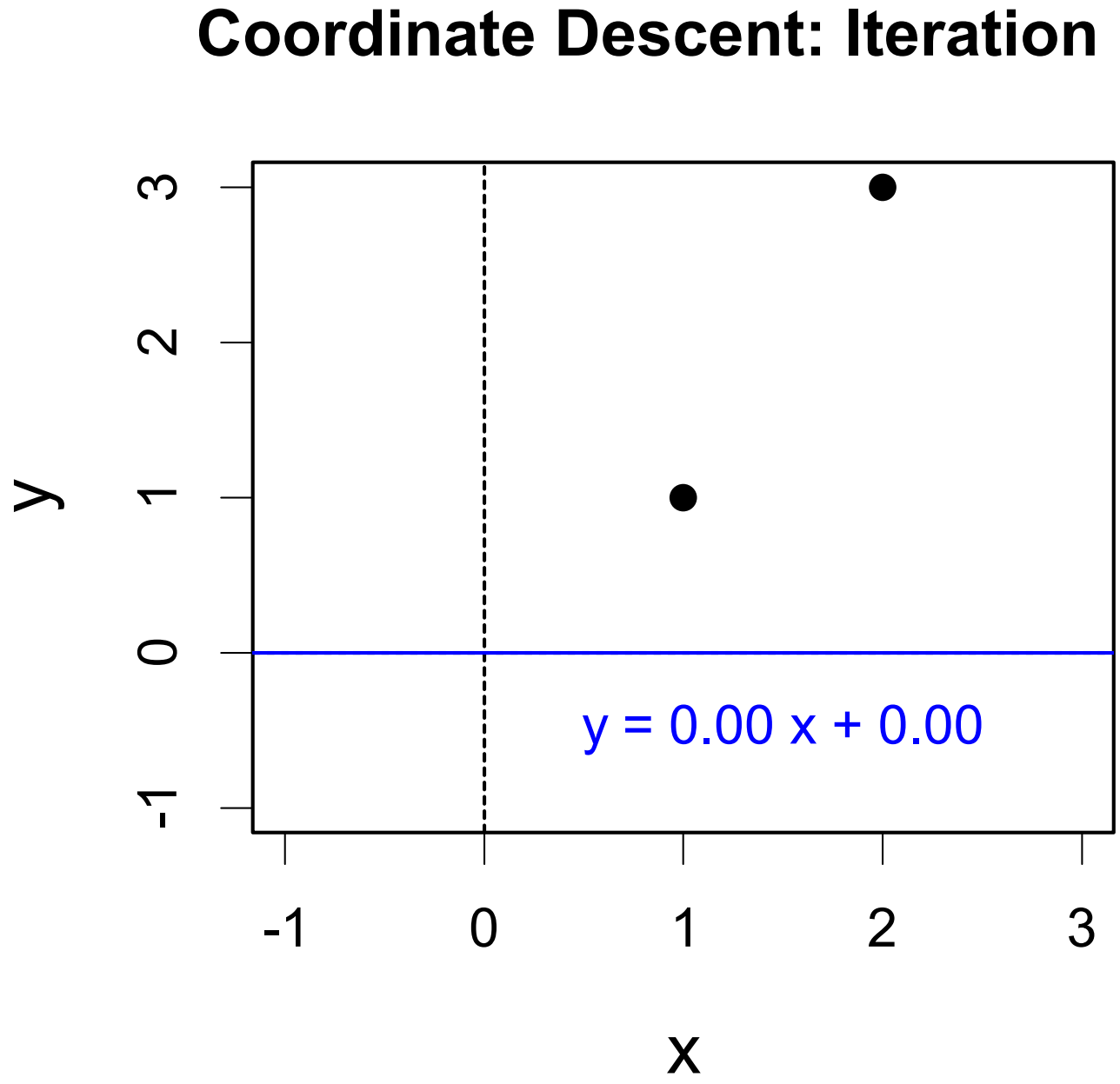
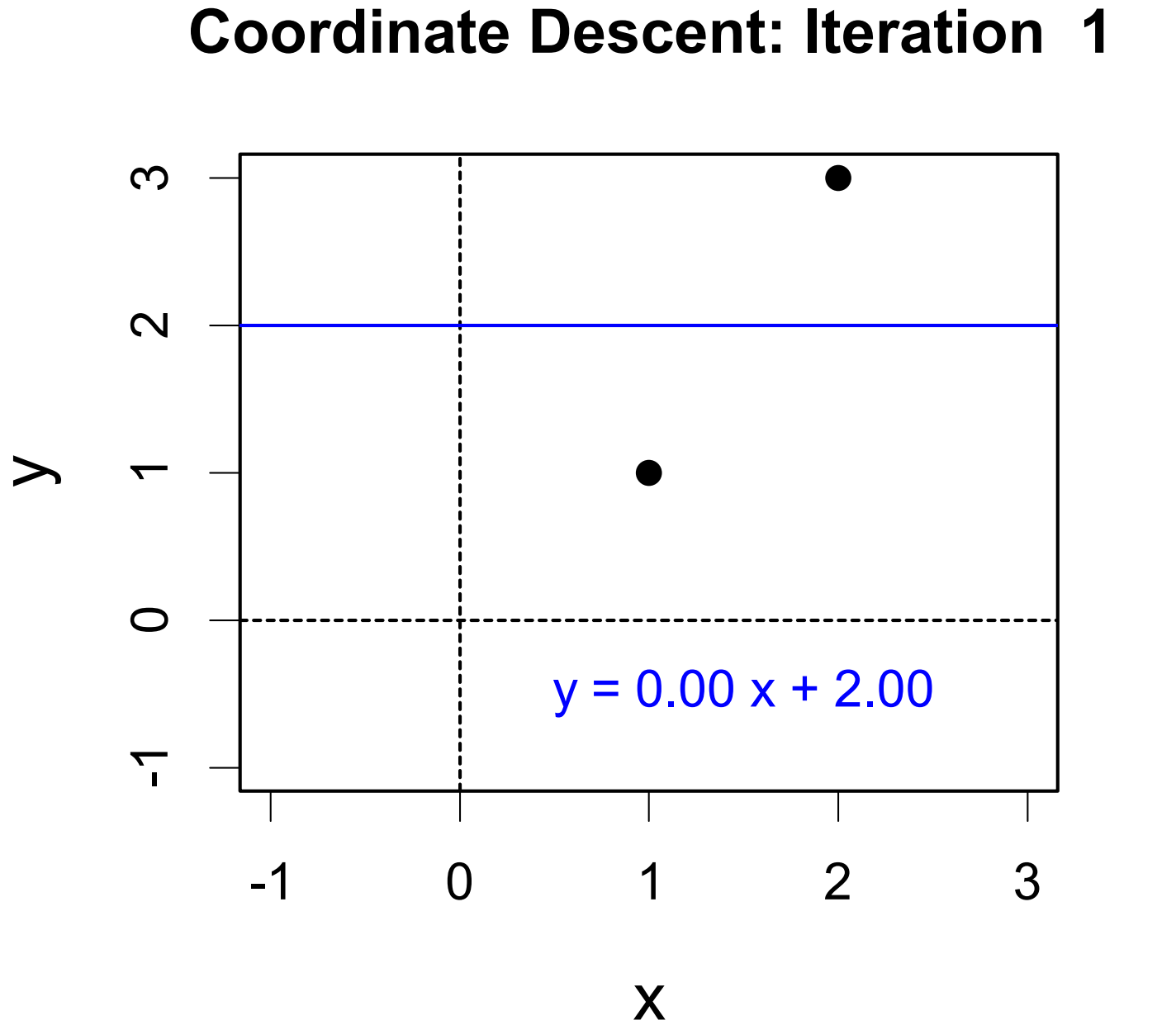
Equation form: $y = mx + b$

Best fit $\rightarrow$ minimize the sum of squared deviations

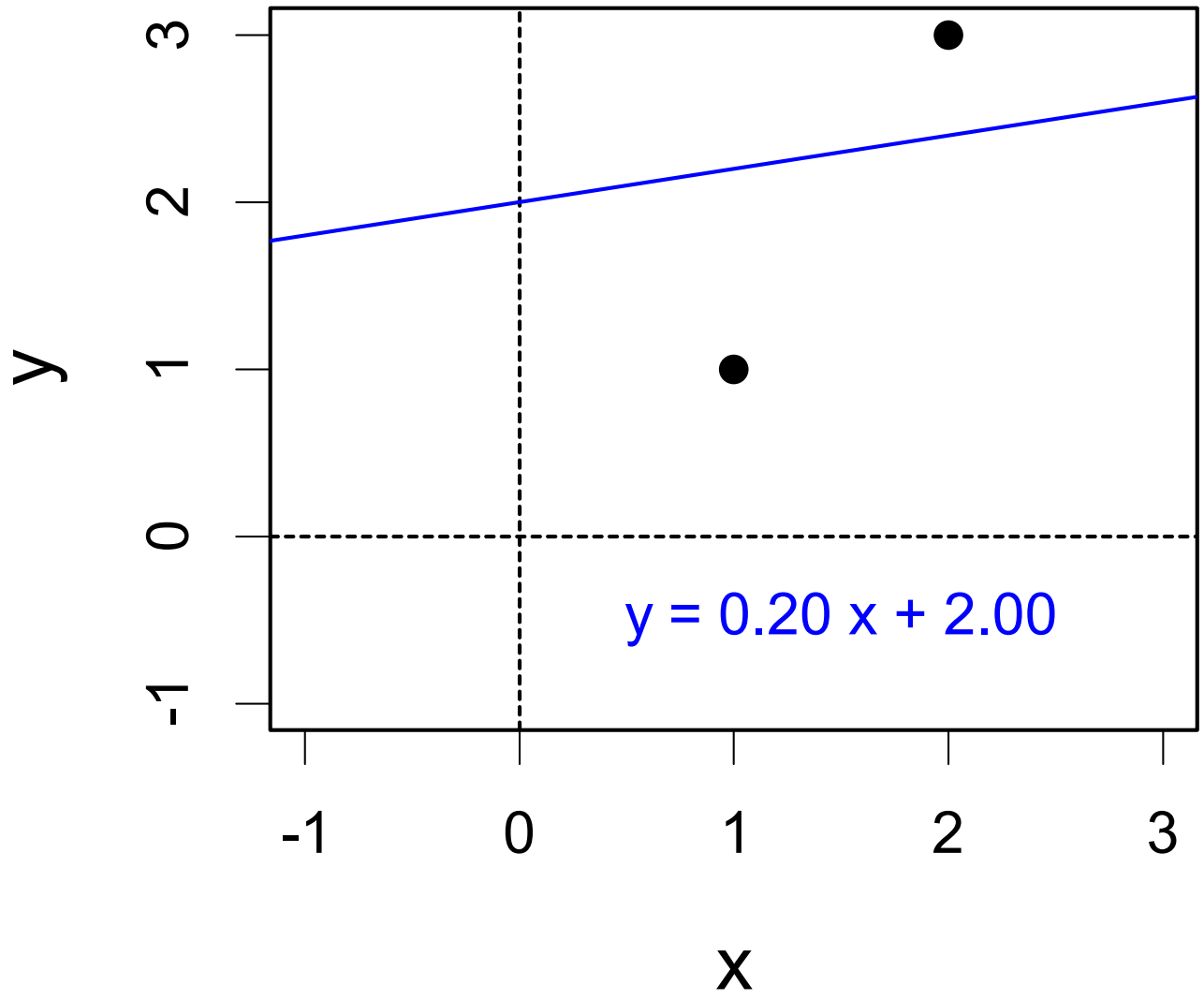
$$L(m, b) = (1 - m - b)^2 + (3 - 2m - b)^2$$

the “loss” function

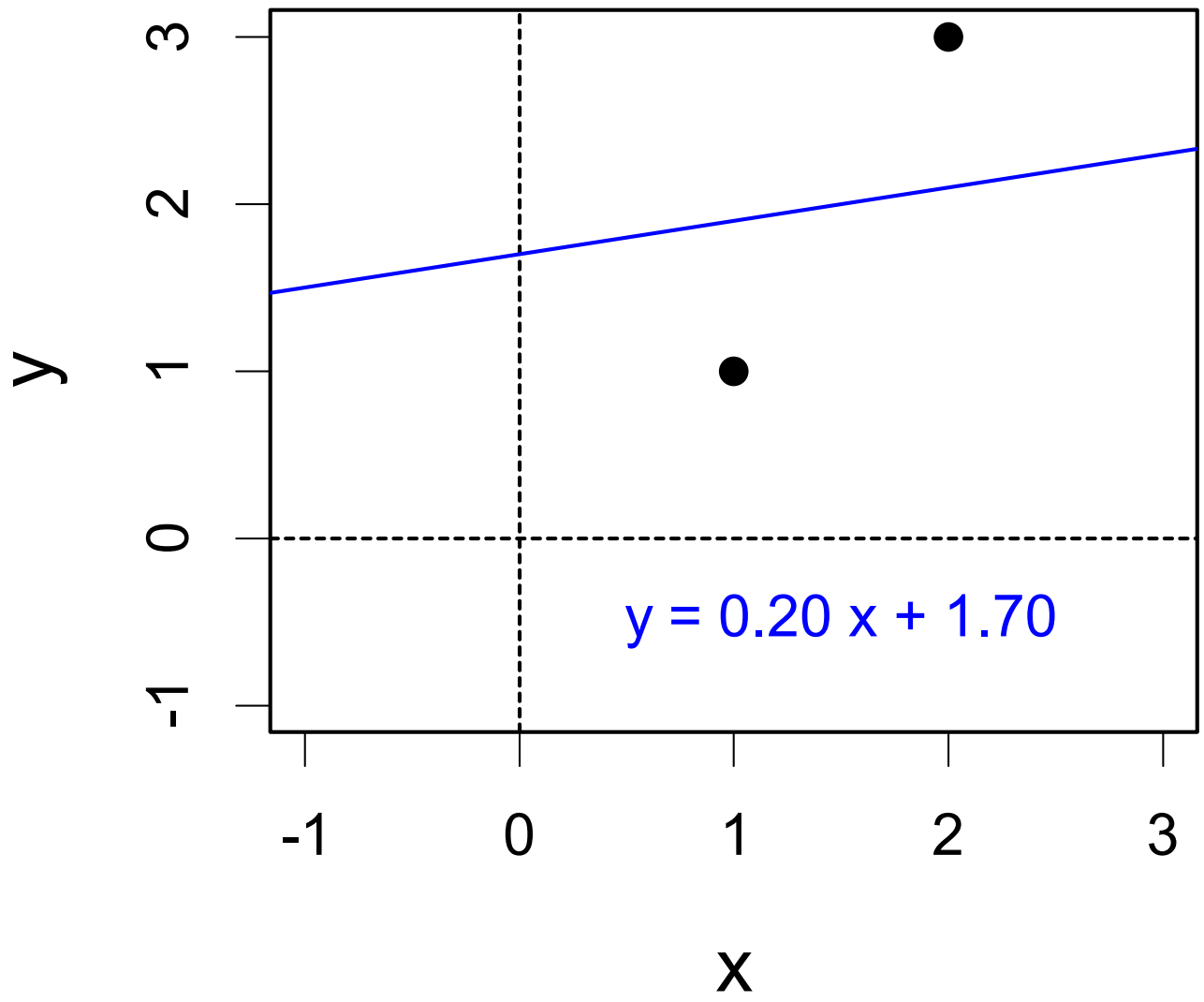

Coordinate Descent: Iteration 0
y
3
2
1
0
-1
y = 0.00 x + 0.00
-1
0
1
2
3
x


Coordinate Descent: Iteration 1
y
x
3
2
1
0
-1
-1
0
1
2
3
y = 0.00 x + 2.00

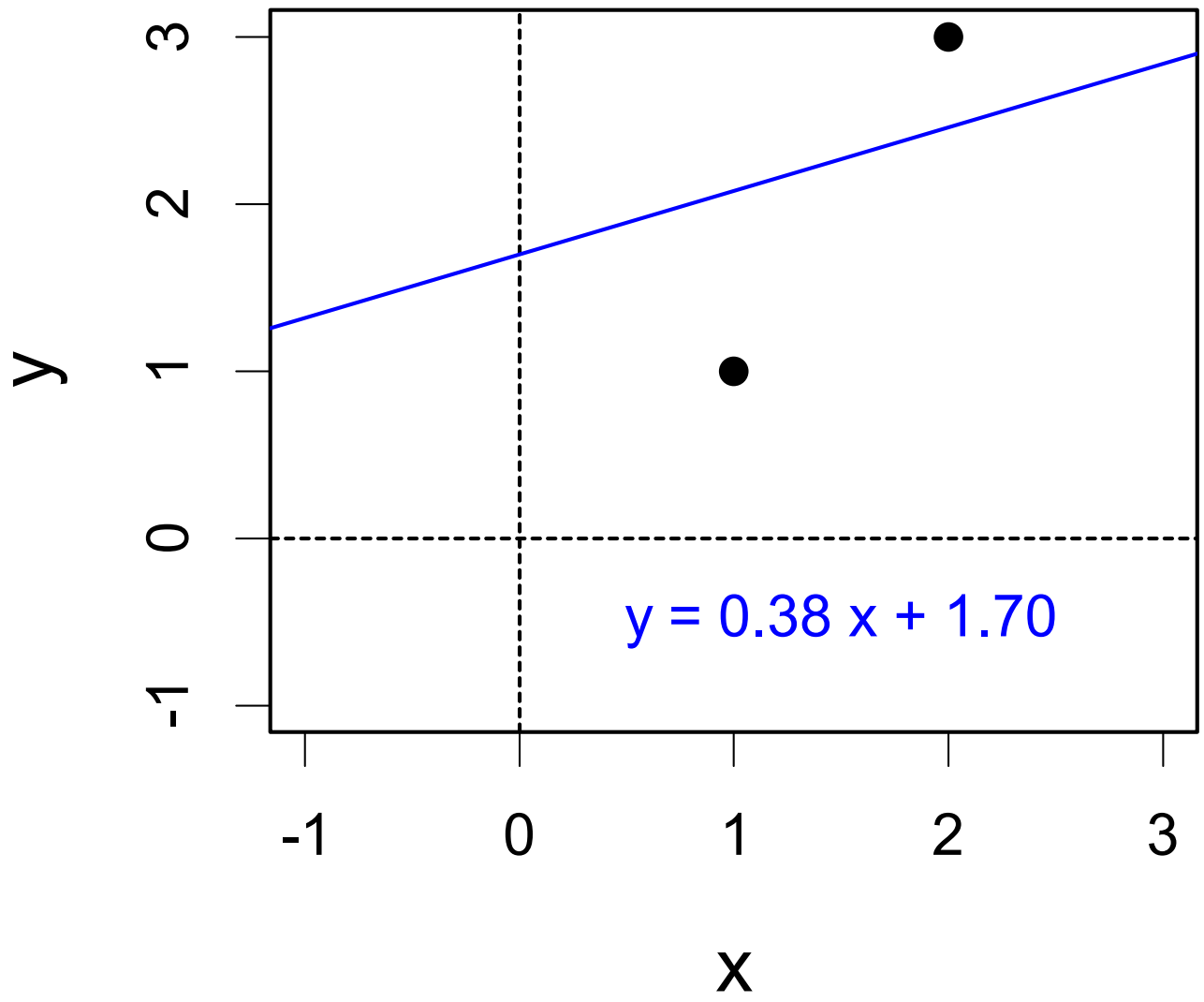
Coordinate Descent: Iteration 2

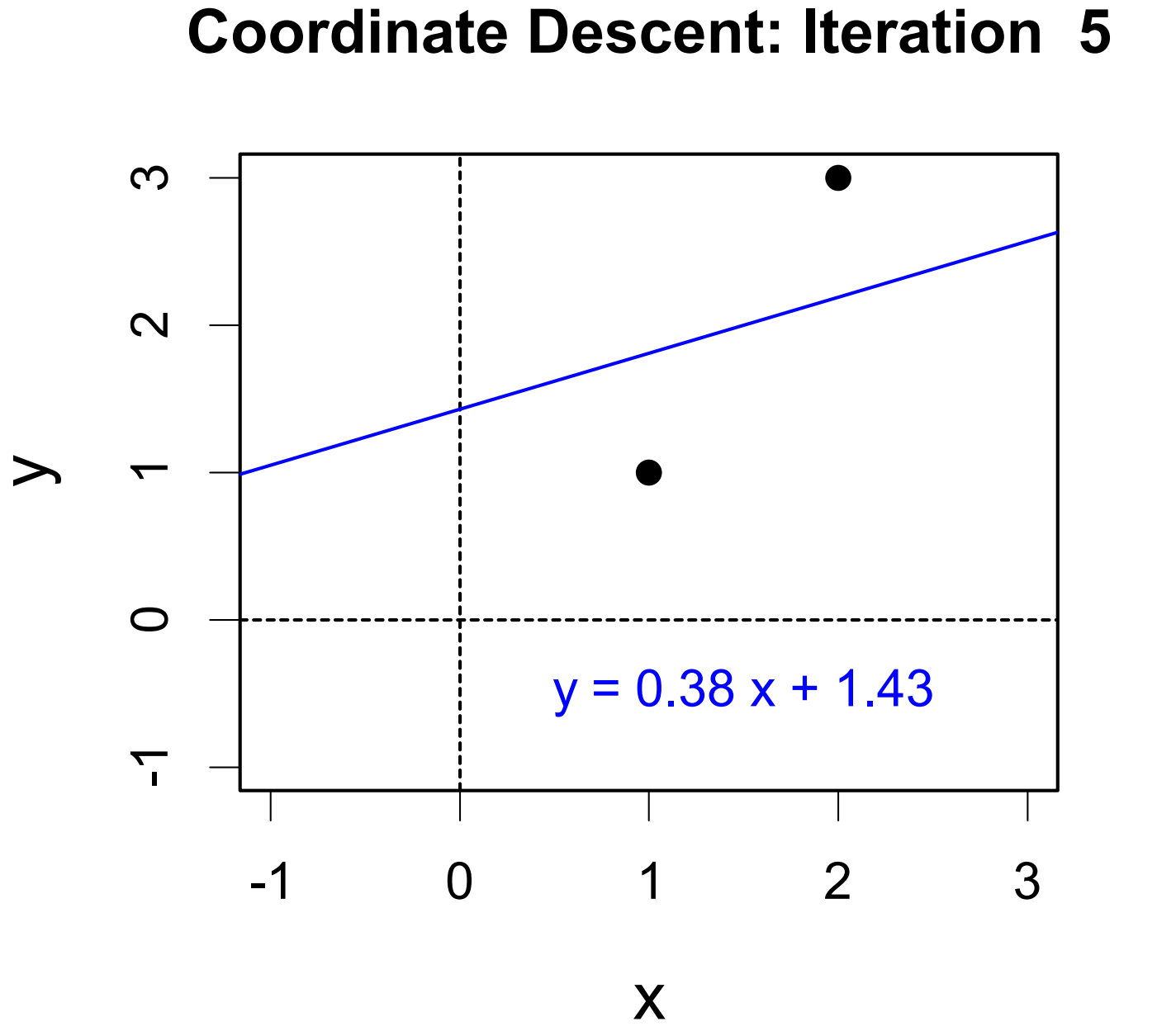


Coordinate Descent: Iteration 3

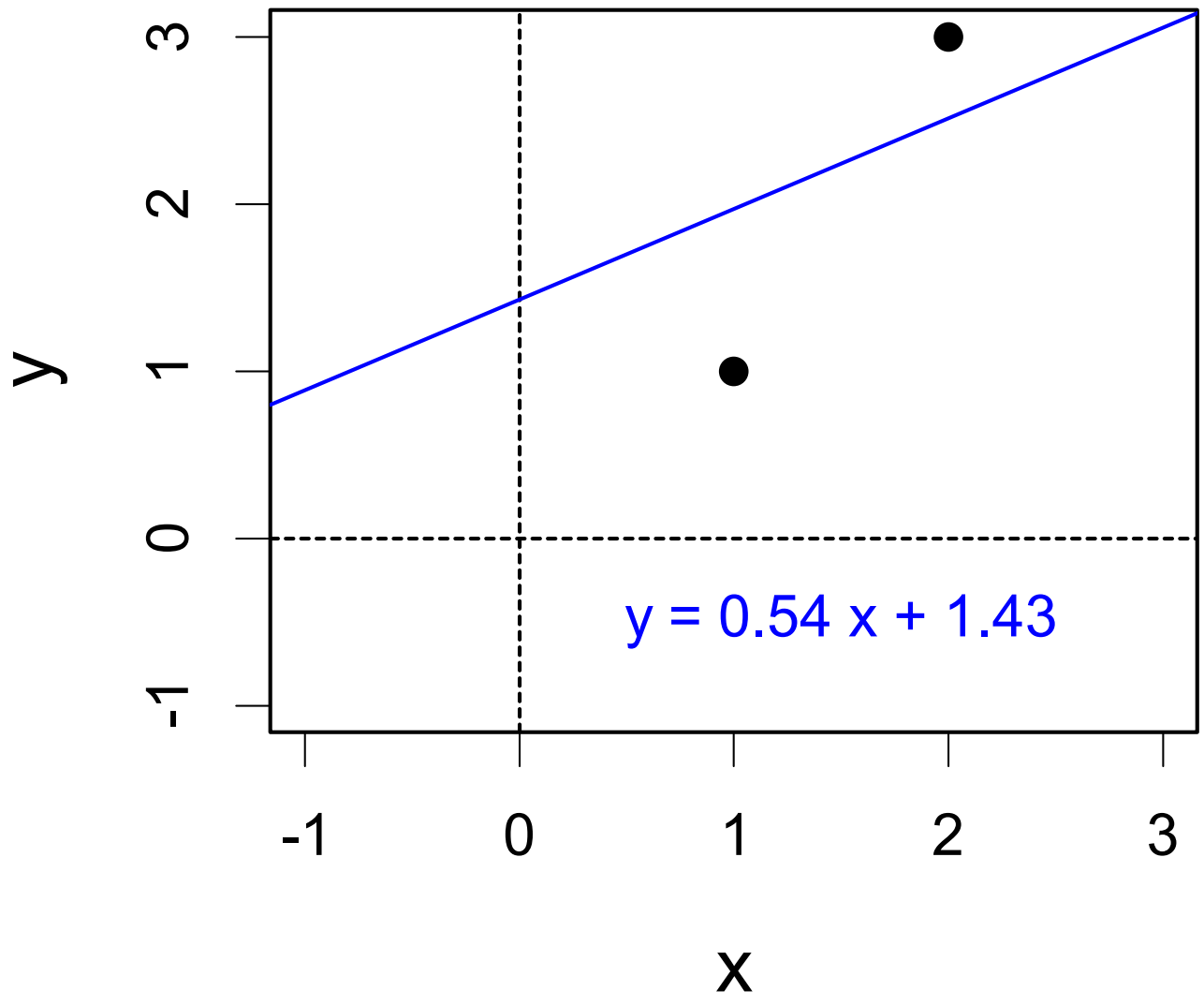


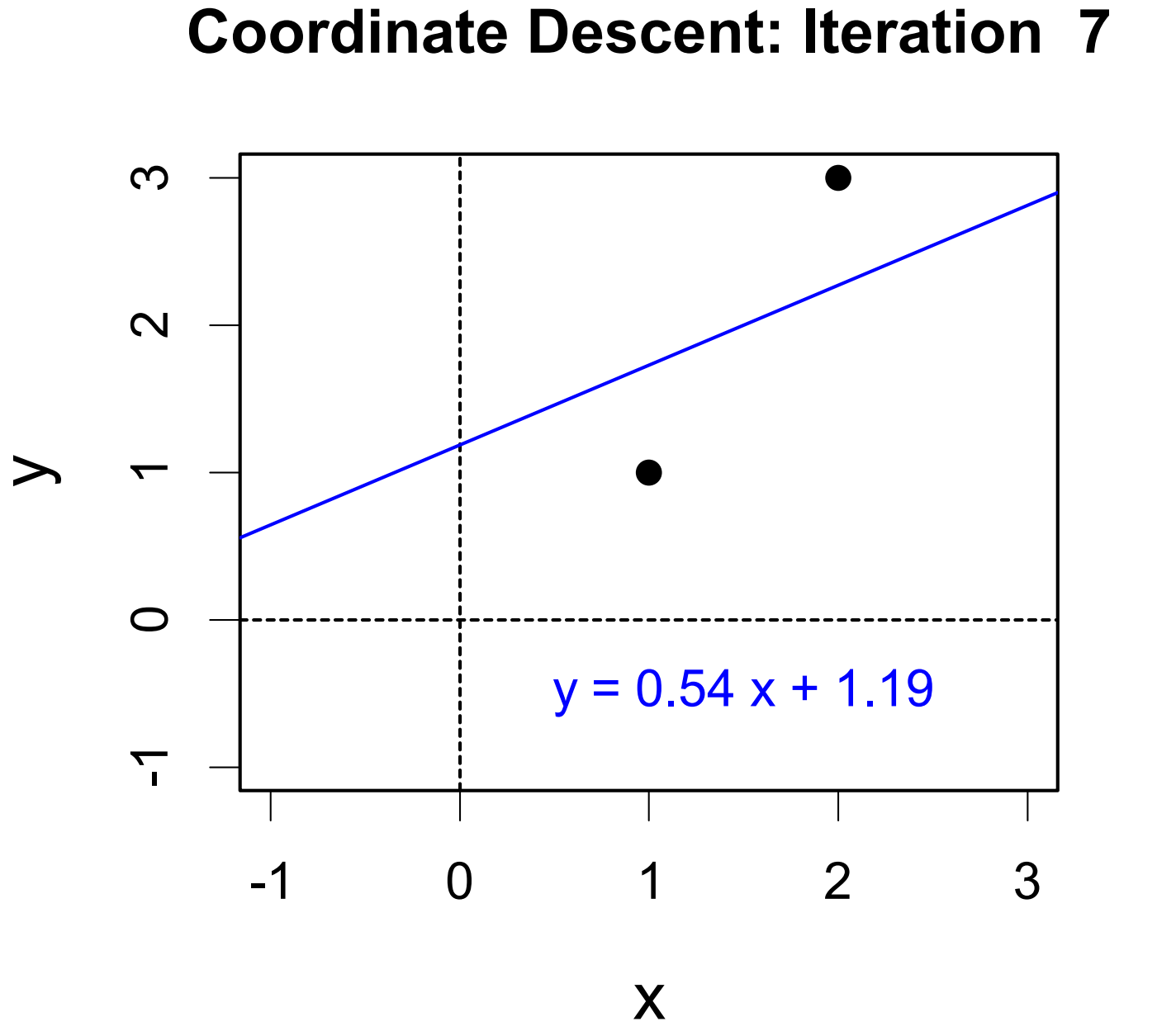
Coordinate Descent: Iteration 4

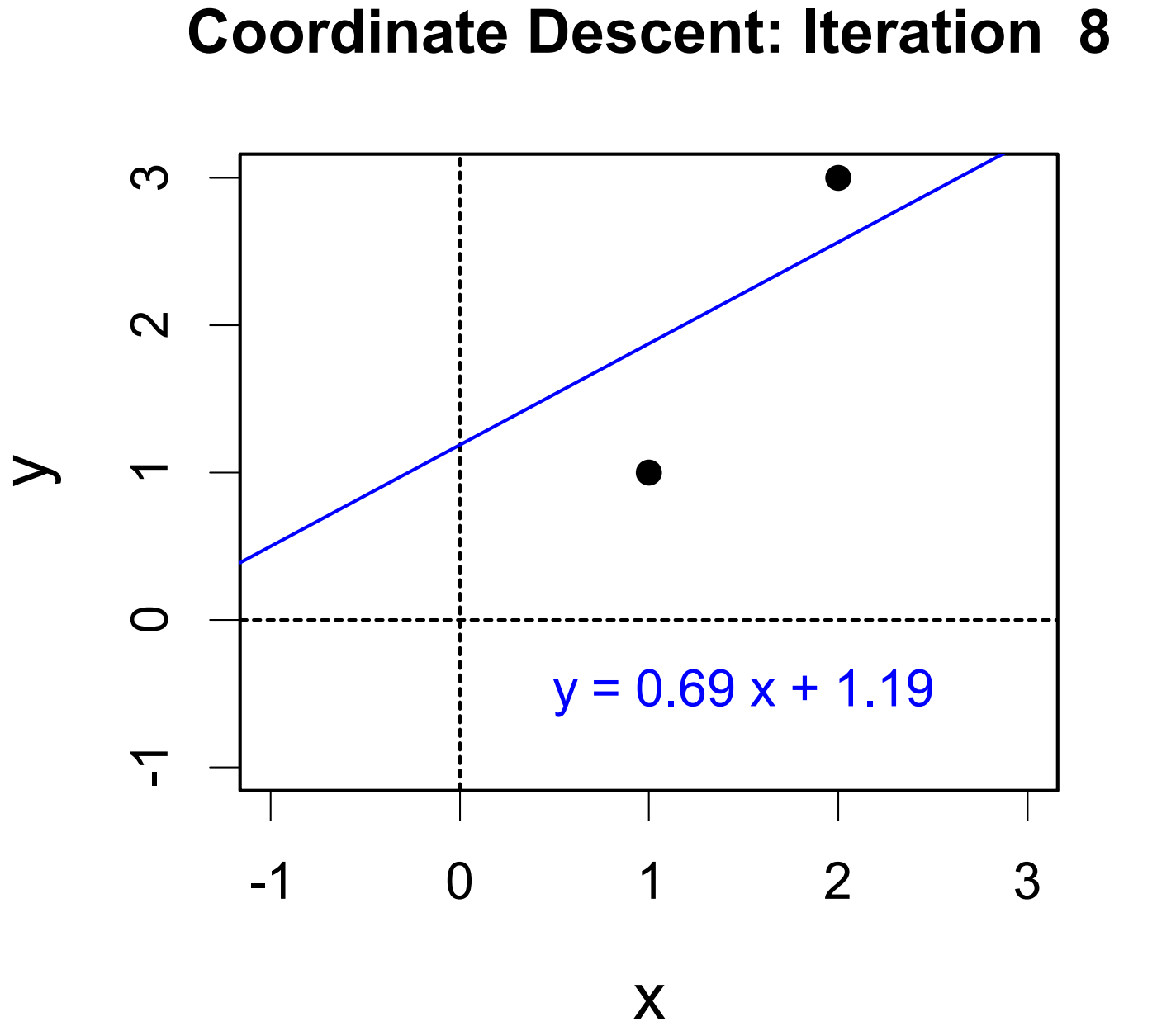


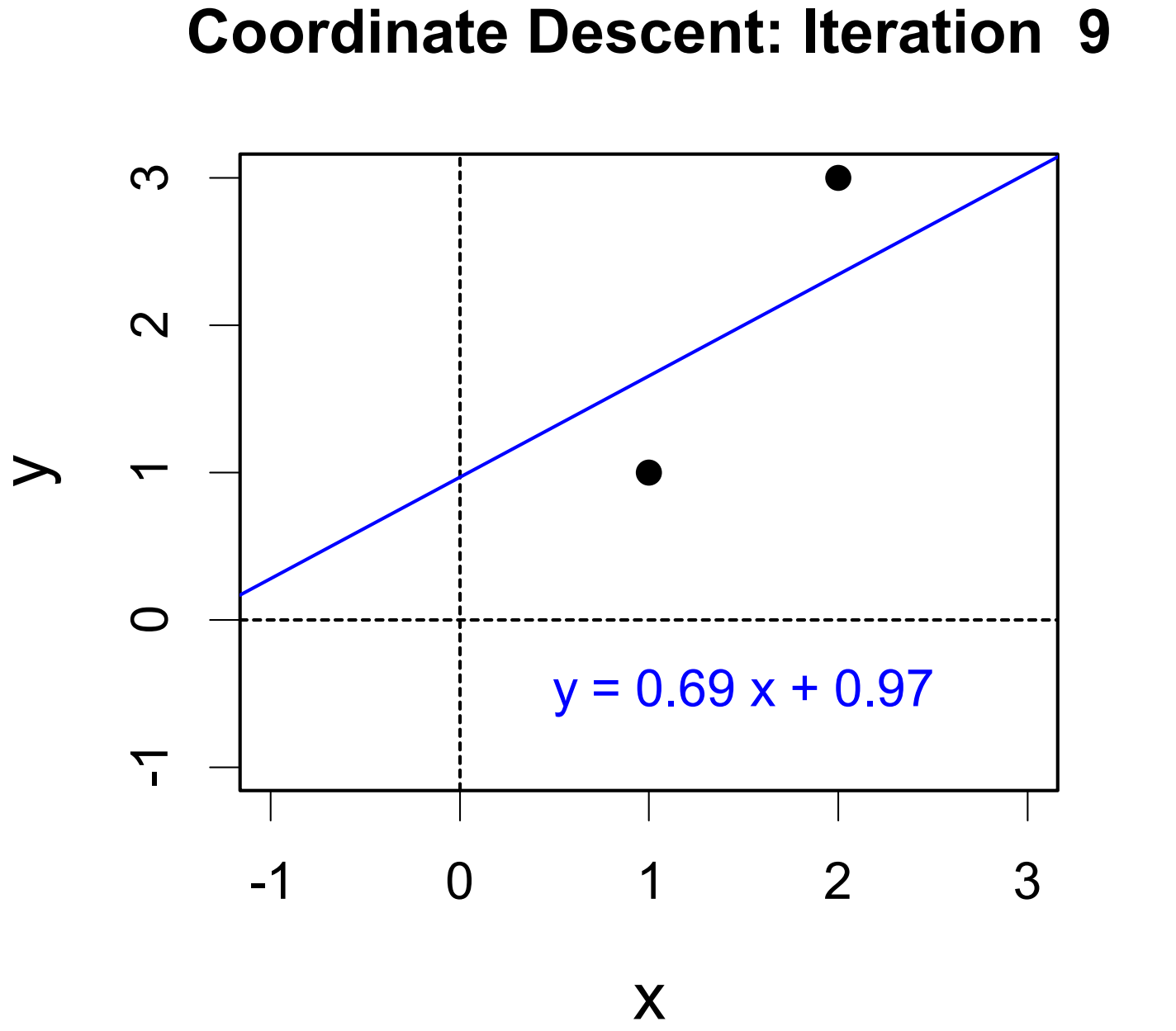

Coordinate Descent: Iteration 5
y = 0.38 x + 1.43
y
x
-1
0
1
2
3

Coordinate Descent: Iteration 6

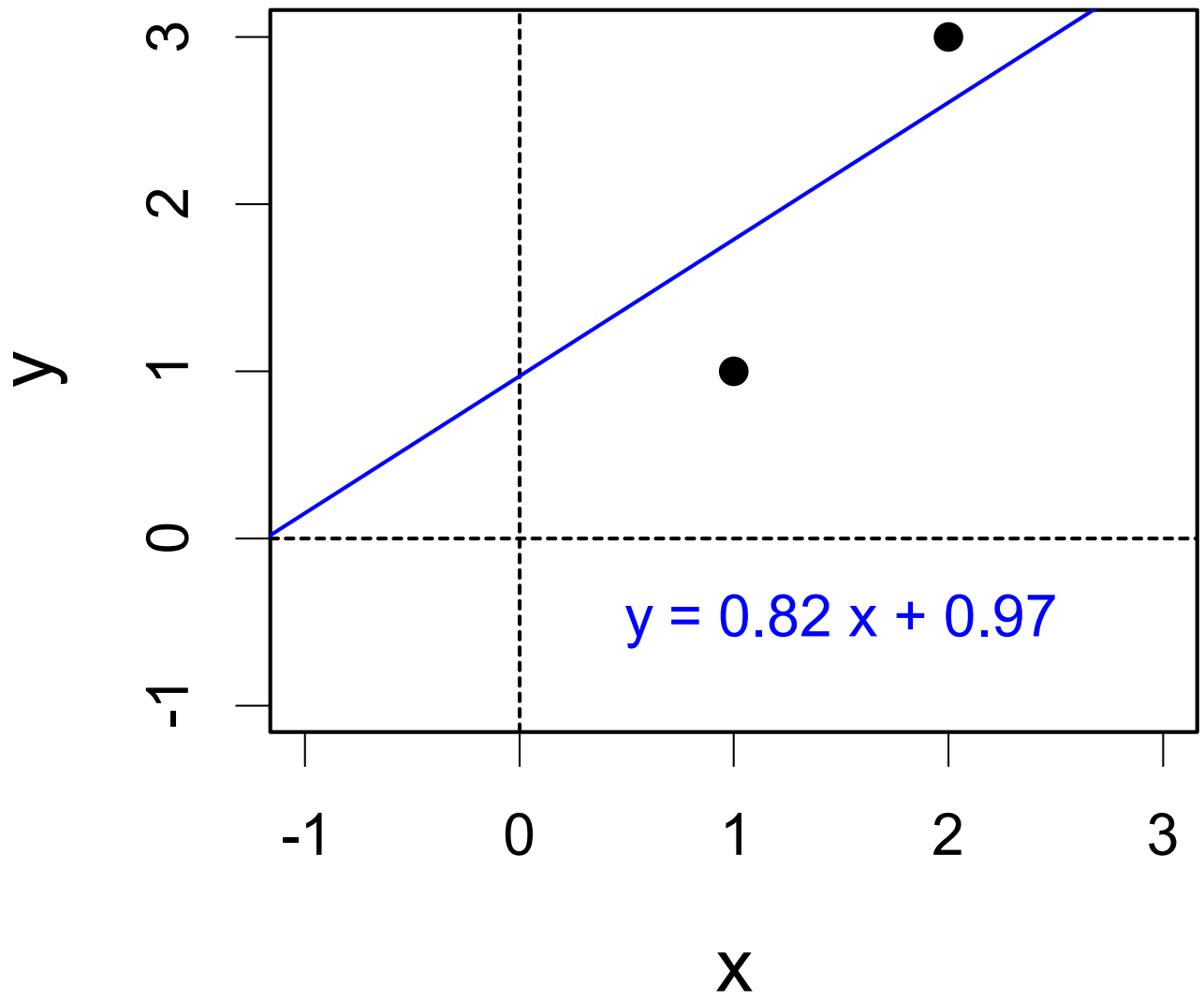



Coordinate Descent: Iteration 7
y
3
2
1
0
-1
y = 0.54 x + 1.19
-1
0
1
2
3
x

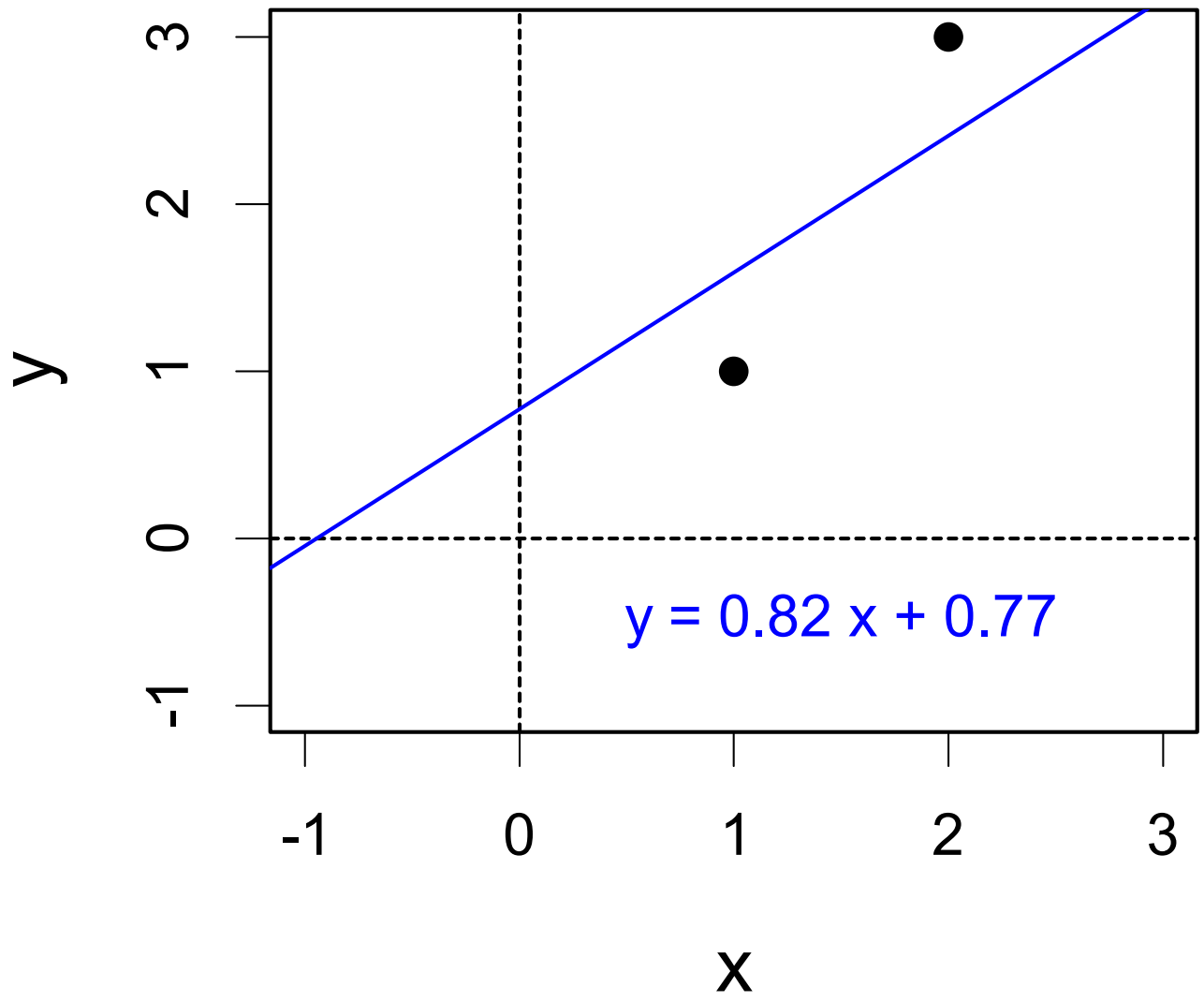

Coordinate Descent: Iteration 8
y
3
2
1
0
-1
y = 0.69 x + 1.19
-1
0
1
2
3
x


Coordinate Descent: Iteration 9
y
3
2
1
0
-1
y = 0.69 x + 0.97
-1
0
1
2
3
x

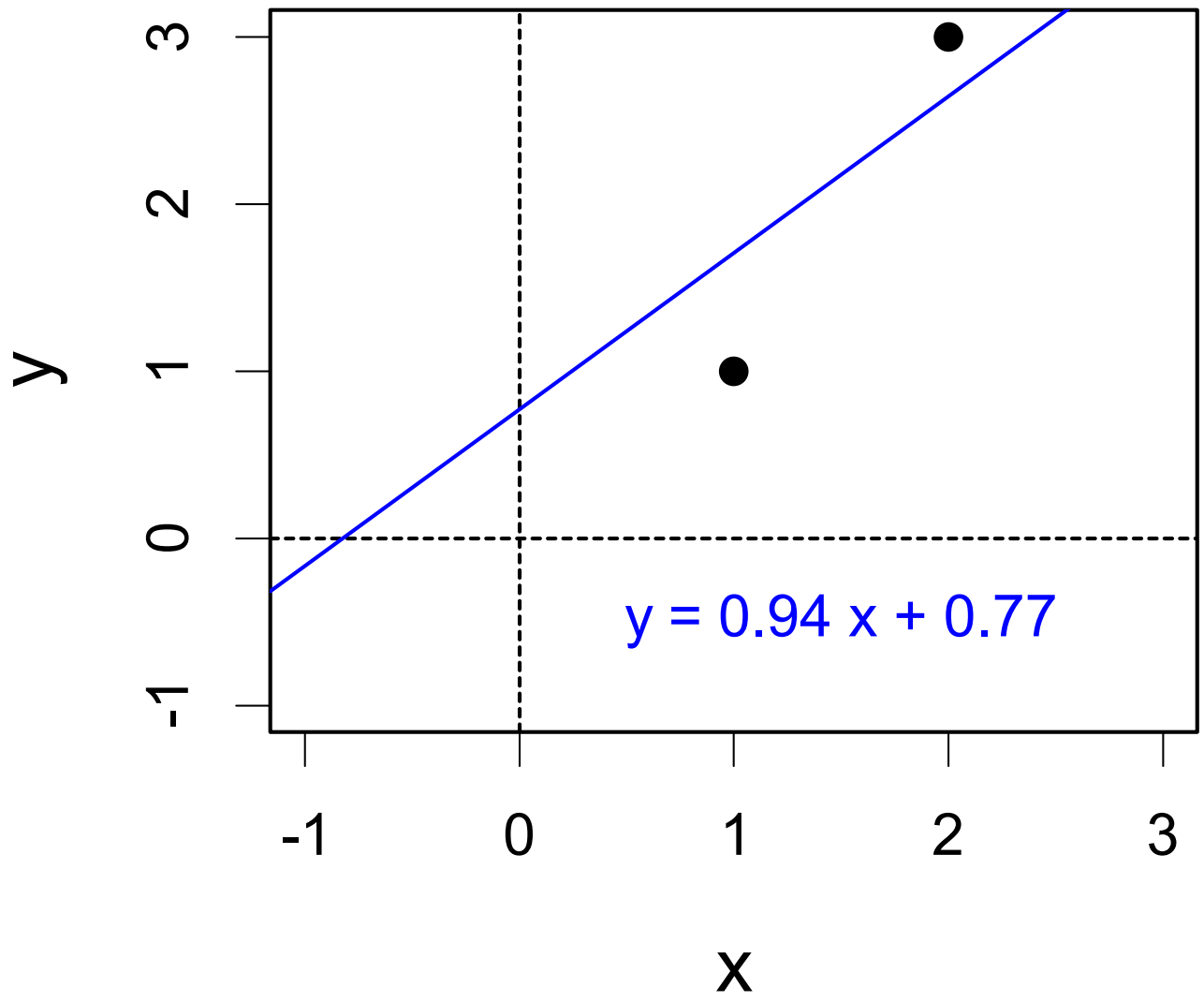
Coordinate Descent: Iteration 10



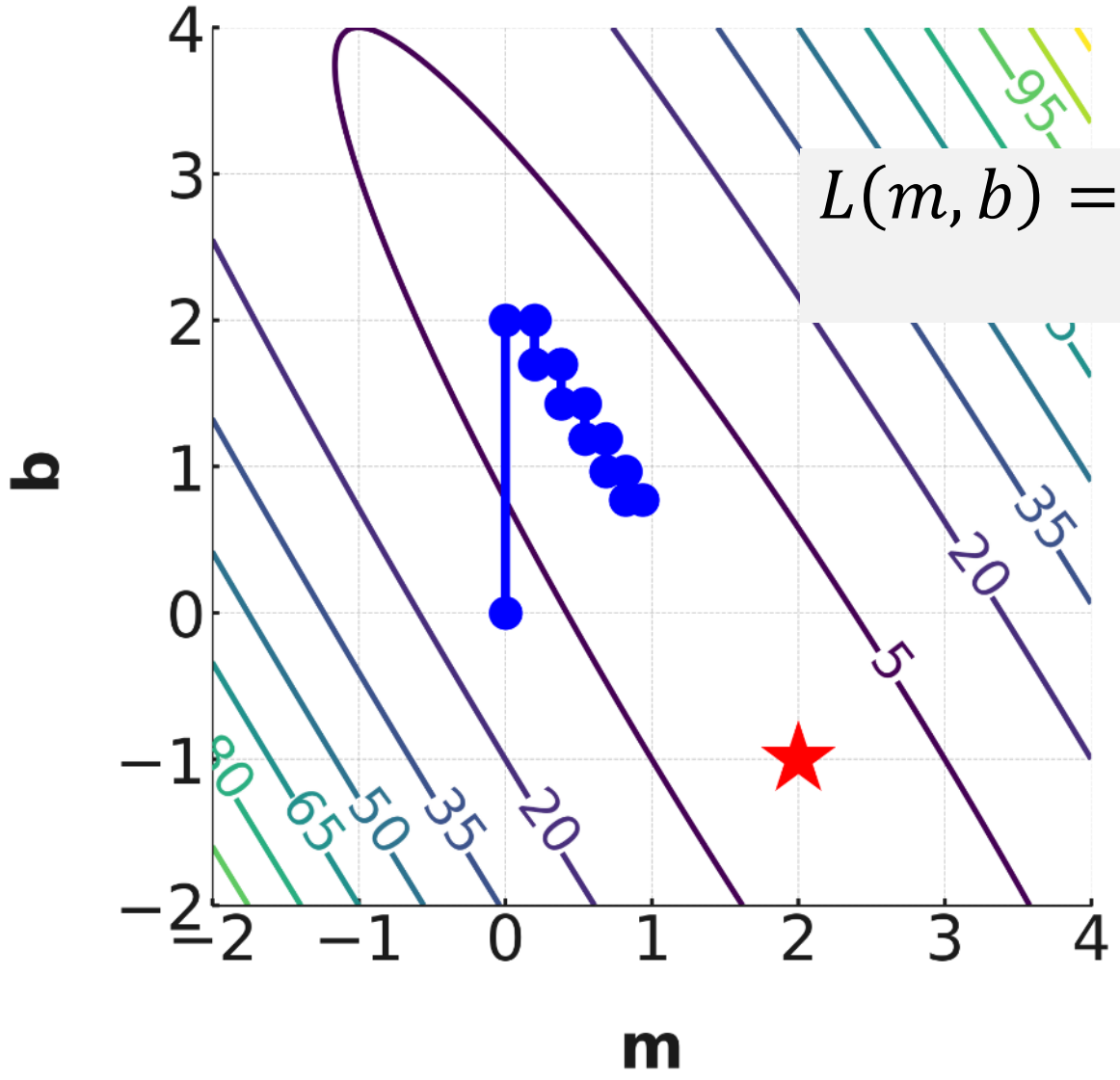
Coordinate Descent: Iteration 11



Coordinate Descent: Iteration 12

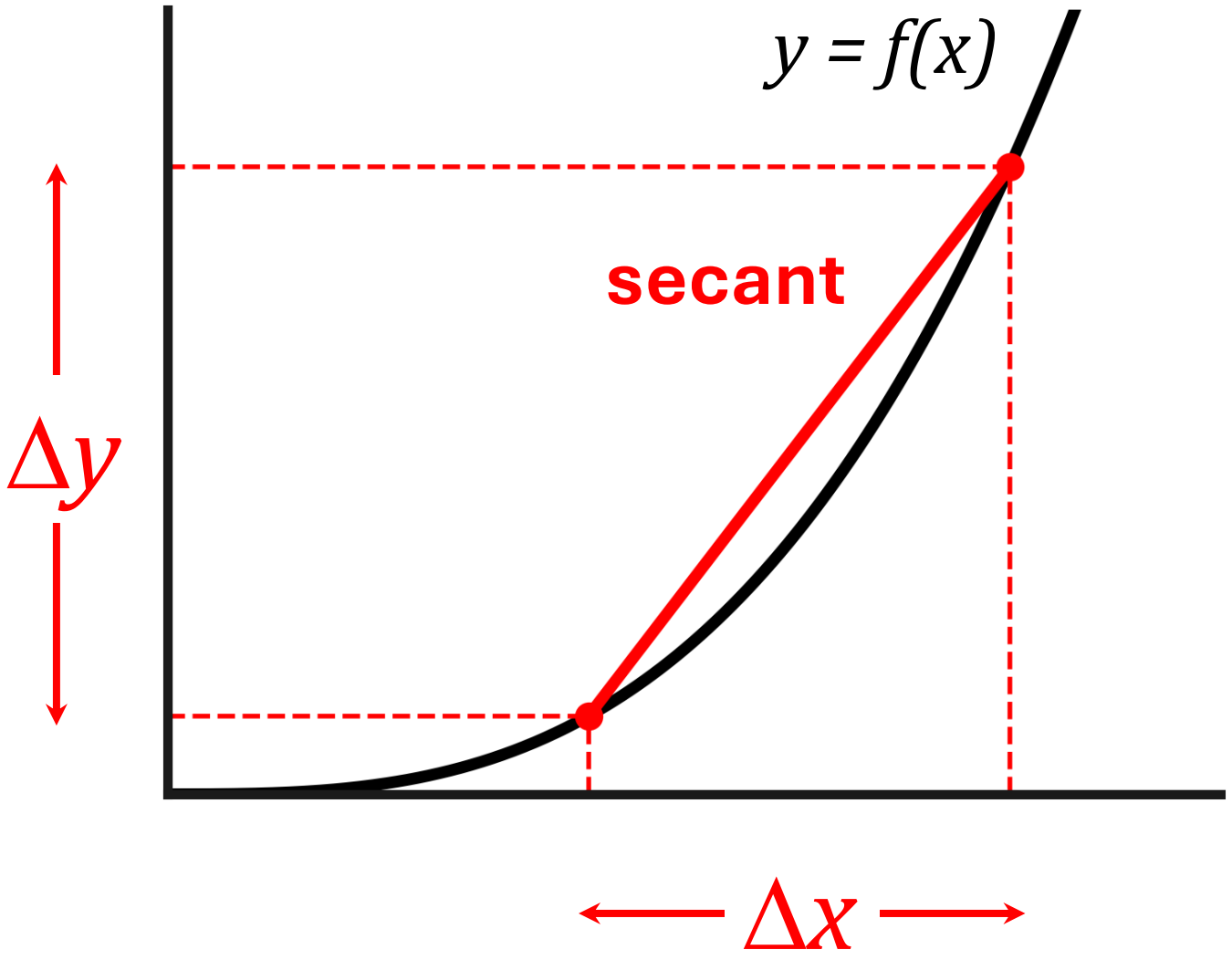


Coordinate Descent: Trace Through Loss Contours



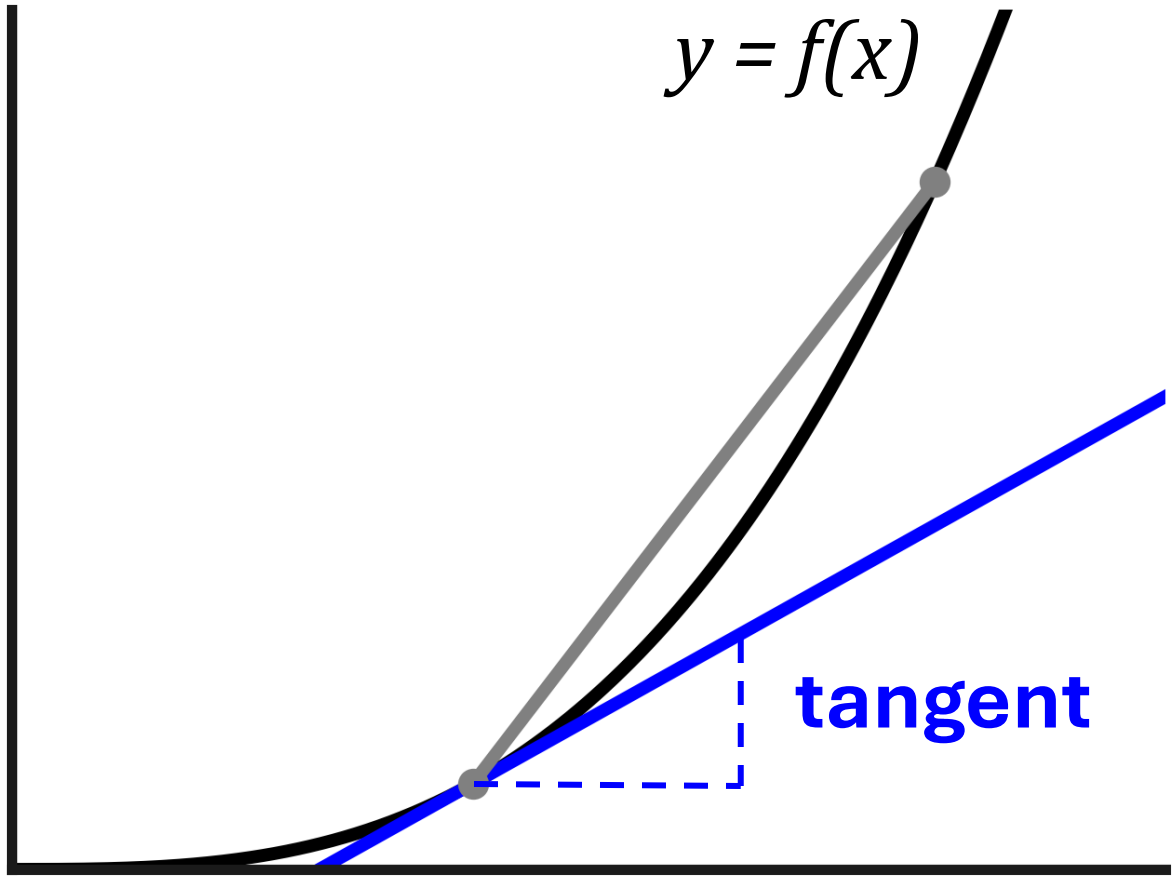
$$L(m,b) = (1-m-b)^2 + (3-2m-b)^2$$

Differentiation



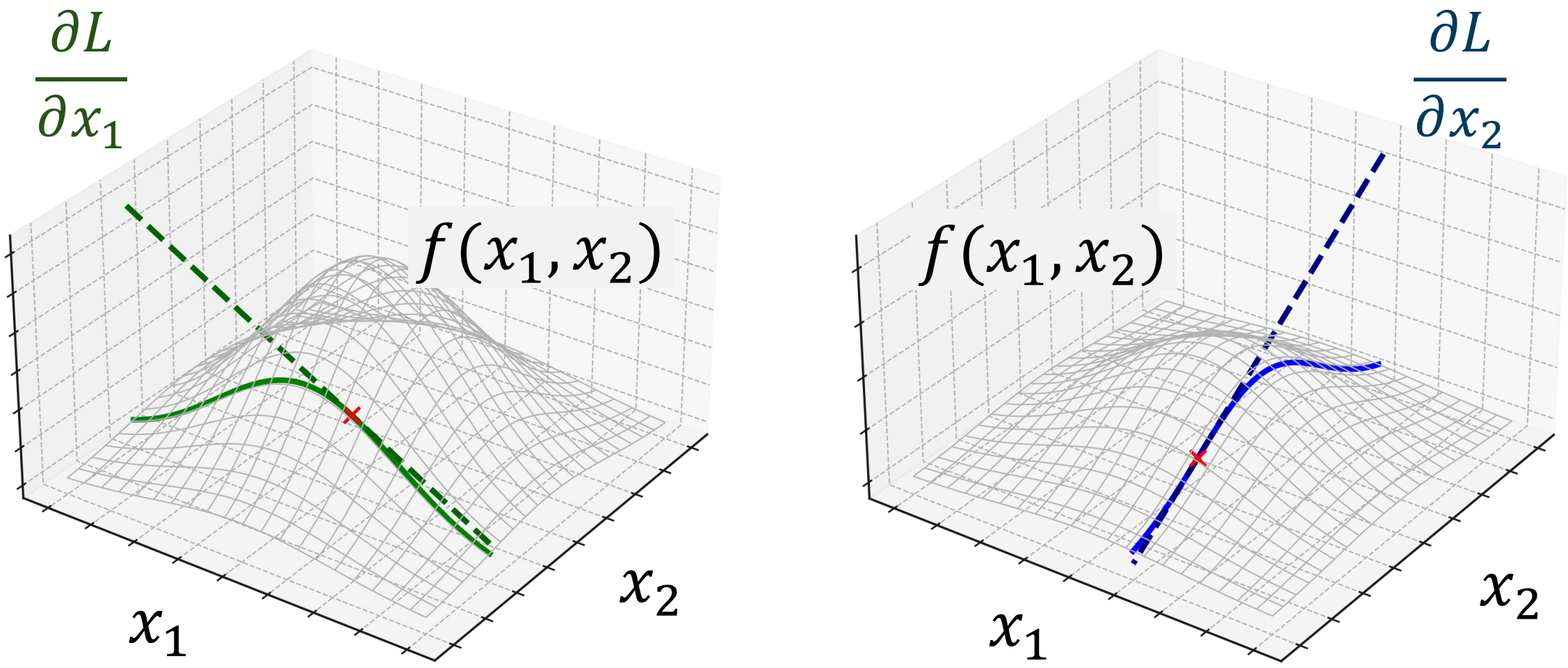
$$\frac{\Delta y}{\Delta x} = \text{average rate of change}$$

Differentiation



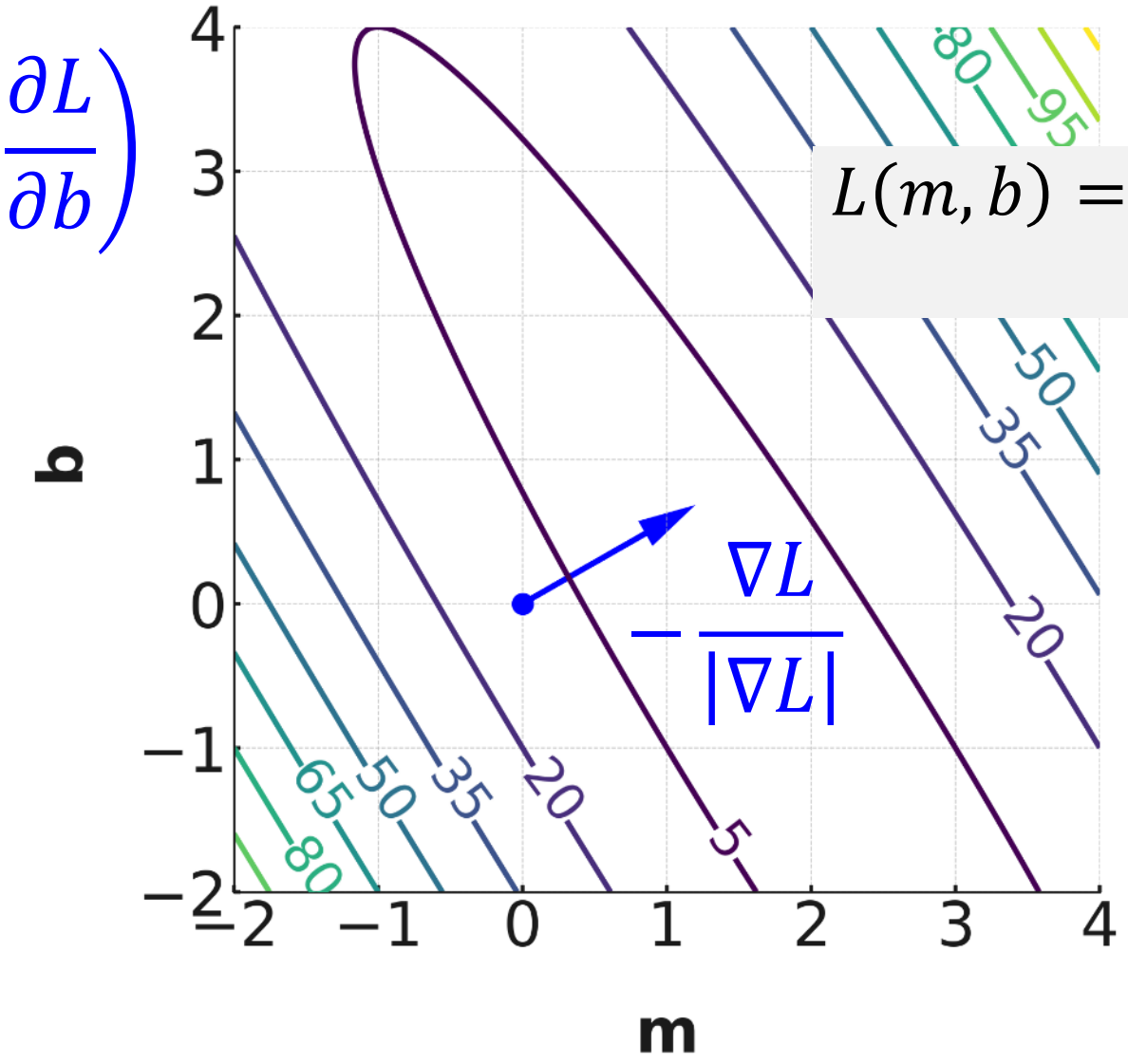
$\frac{df}{dx}$ = local rate of change

Differentiation: Multivariable Functions



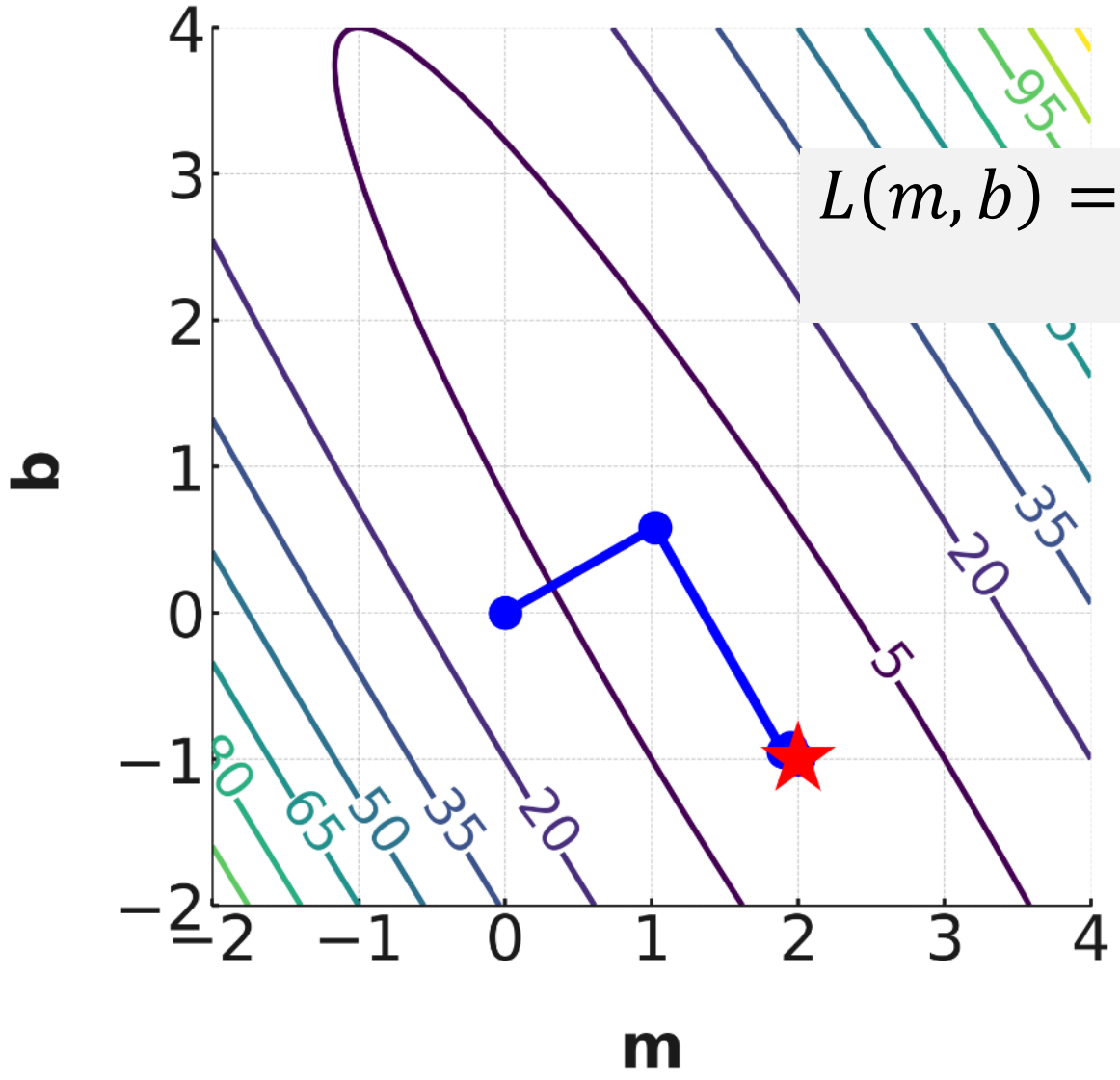
Gradient Vector on Loss Contours

$$\nabla L = \left(\frac{\partial L}{\partial m}, \frac{\partial L}{\partial b}\right)$$



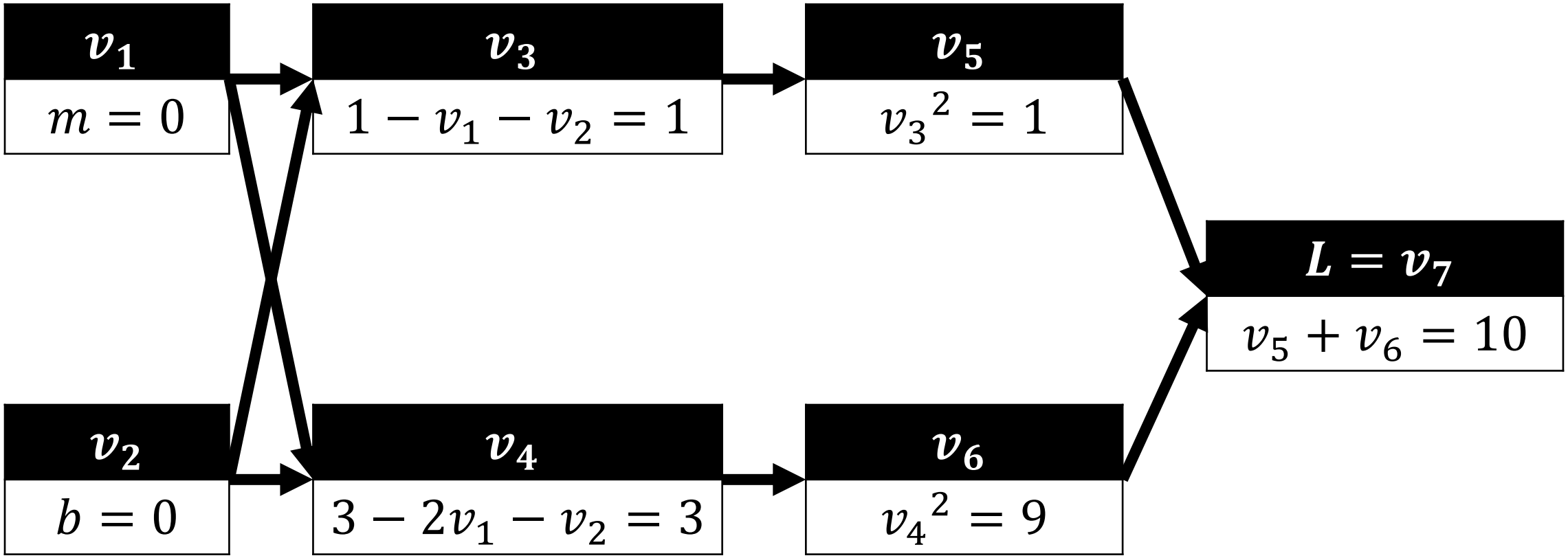
$$L(m,b) = (1-m-b)^2 + (3-2m-b)^2$$

Gradient Descent: Trace Through Loss Contours

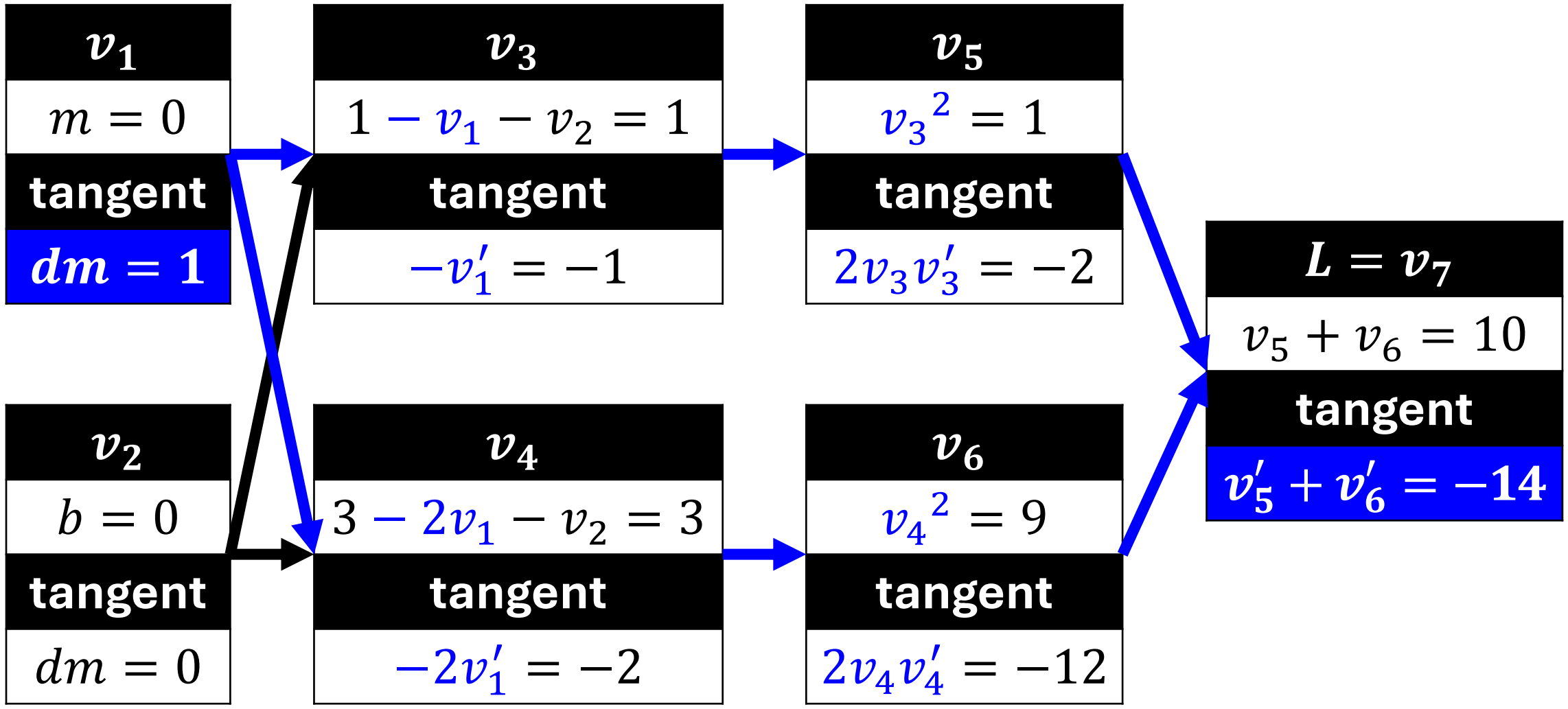


$$L(m,b) = (1-m-b)^2 + (3-2m-b)^2$$

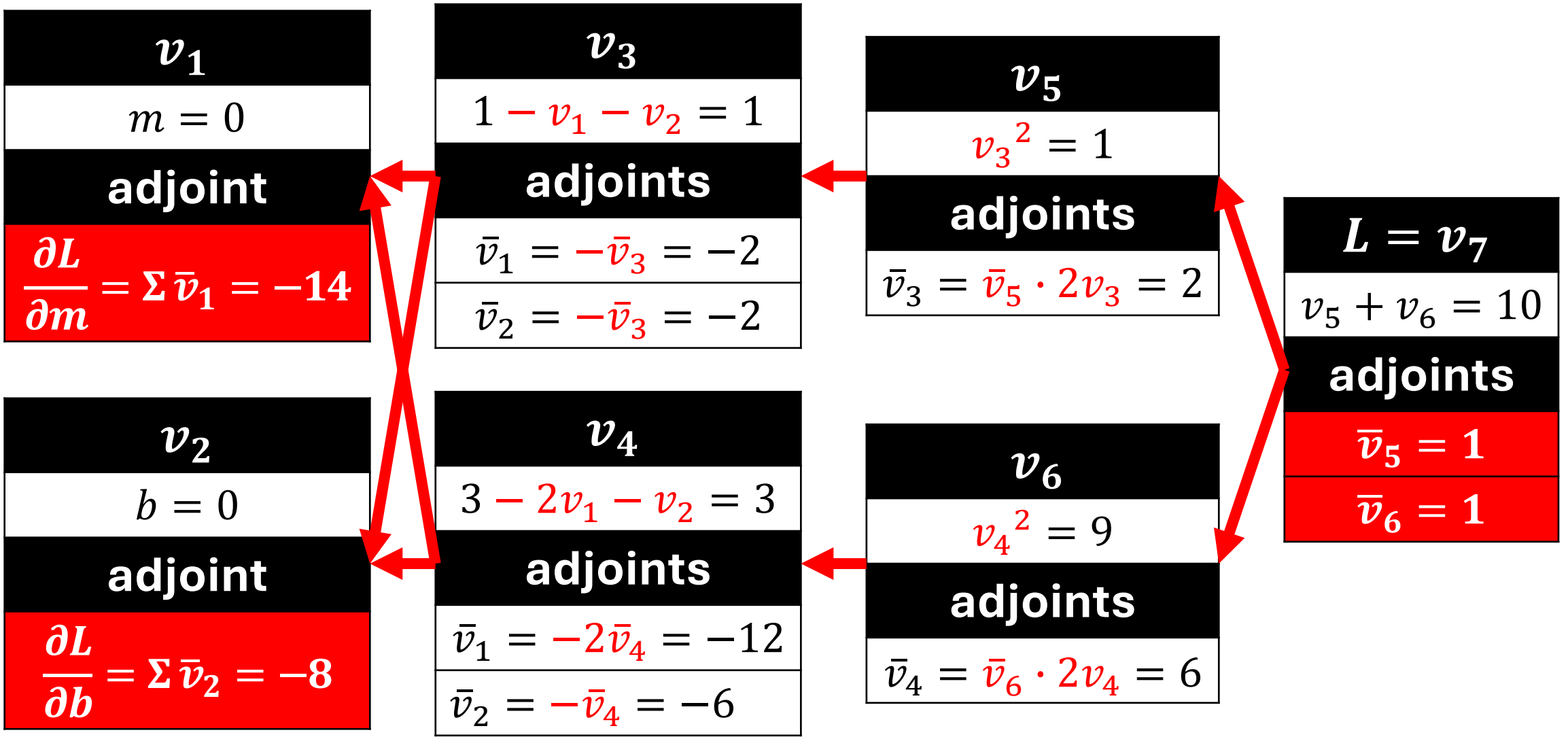
Computational Graph

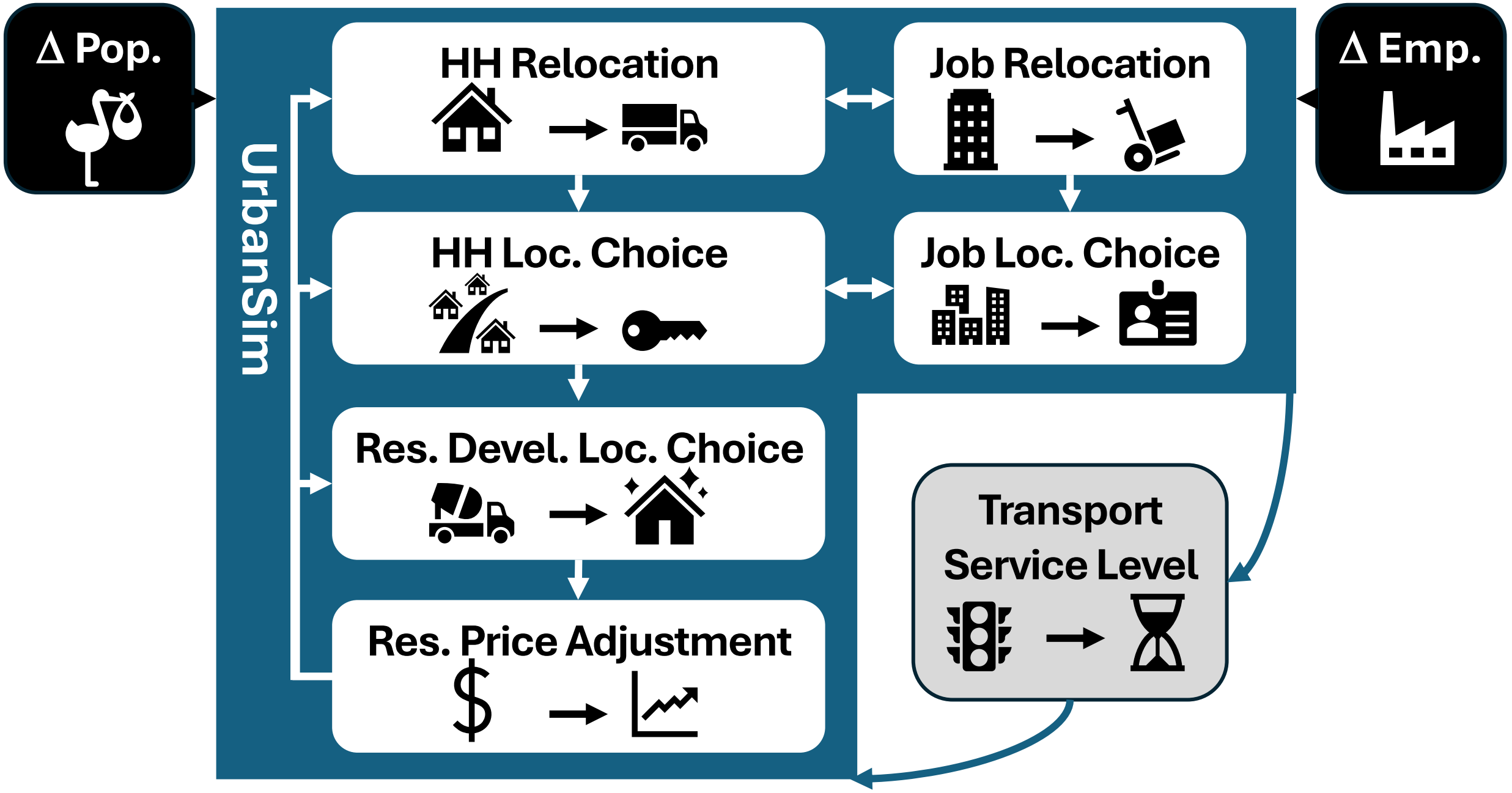


Automatic Differentiation



(Reverse) Automatic Differentiation




Δ Pop.
Δ Emp.
UrbanSim
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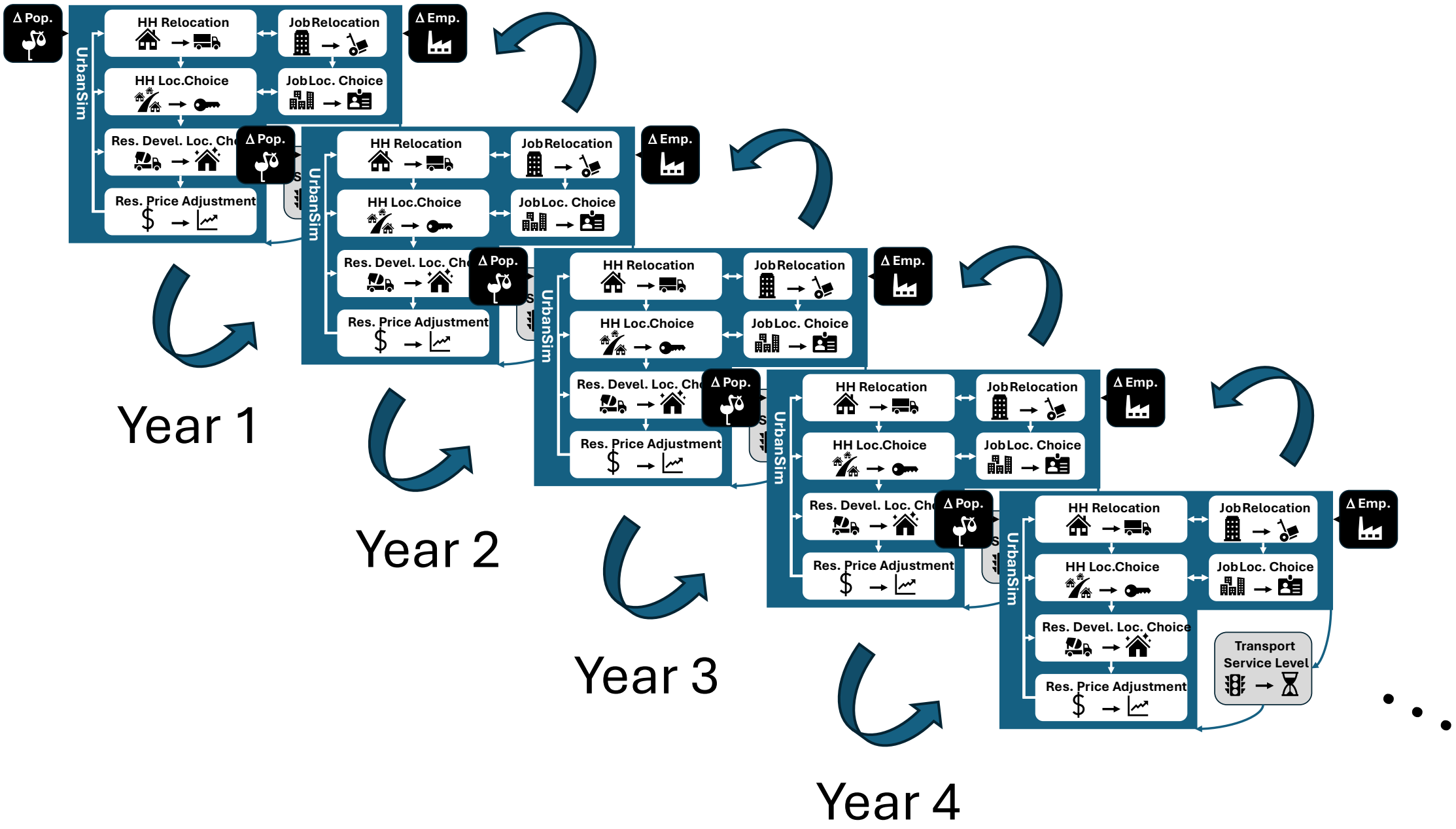
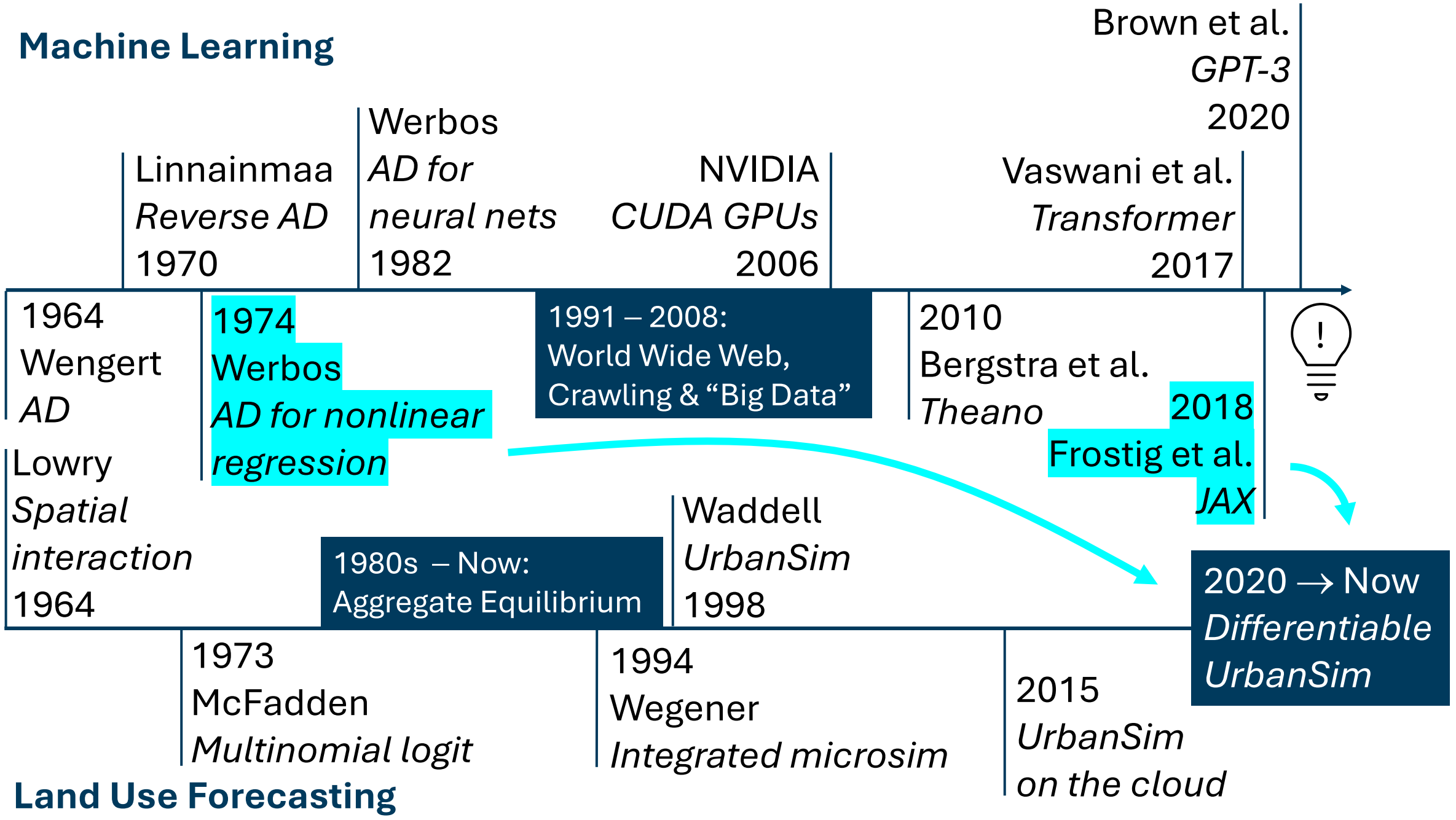
Job Relocation
HH Loc. Choice
Job Loc. Choice
Res. Devel. Loc. Choice
Res. Price Adjustment
Transport
Service Level


Δ Pop.
UrbanSim
HH Relocation
Job Relocation
Δ Emp.
HH Loc.Choice
Job Loc. Choice
Res. Devel. Loc. Choice
Res. Price Adjustment
Transport Service Level
Year 1
Year 2
Year 3
Year 4


Machine Learning
Brown et al.
GPT-3
2020
Werbos
AD for
neural nets
1982
Linnainmaa
Reverse AD
1970
NVIDIA
CUDA GPUs
2006
Vaswani et al.
Transformer
2017
1964
Wengert
AD
1974
Werbos
AD for nonlinear
regression
1991 – 2008:
World Wide Web,
Crawling & "Big Data"
2010
Bergstra et al.
Theano
2018
Frostig et al.
JAX
!
Lowry
Spatial
interaction
1964
1980s – Now:
Aggregate Equilibrium
Waddell
UrbanSim
1998
2020 → Now
Differentiable
UrbanSim
1973
McFadden
Multinomial logit
1994
Wegener
Integrated microsim
2015
UrbanSim
on the cloud
Land Use Forecasting

Accelerator-Oriented Python

- Procedure vectorization
- Automatic differentiation

Domain-Specific Application

- Cloud-based user interface
- Expert engineering support

Editing Variable Definitions

```
area: datasource("sum_acres")
intercept: jnp.ones_like(area)

sov_time:
  skim_matrix(units="mins", suffix="sov")
job_access_30min_sov:
  accessibility(sov_time, jobs, 30)

remaining_res_capacity:
  jnp.clip(res_capacity - res_units, 0.0)

…
```

Prescribing The Loss Function

$$\text{Let } NMSE(v) = \frac{\sum_{z \in \text{zones}} \left(v_{\text{predicted}}(z) - v_{\text{actual}}(z)\right)^2 / |\text{zones}|}{\text{Var}(v_{\text{actual}})}$$

$$\text{Then } L = \left[\begin{array}{c} NMSE(\Delta Price)/2 + NMSE(\Delta Rent)/2 \\ + NMSE(\Delta Units_{own})/2 + NMSE(\Delta Units_{rent})/2 \\ + NMSE(\Delta HH_{own})/2 + NMSE(\Delta HH_{rent})/2 \\ + \Sigma_{i \in \text{incomes}} NMSE(\Delta HH_i)/|\text{incomes}| \\ + \Sigma_{s \in \text{sectors}} NMSE(\Delta Emp_s)/|\text{sectors}| \end{array} \right] /5$$

Initializing Model Specification

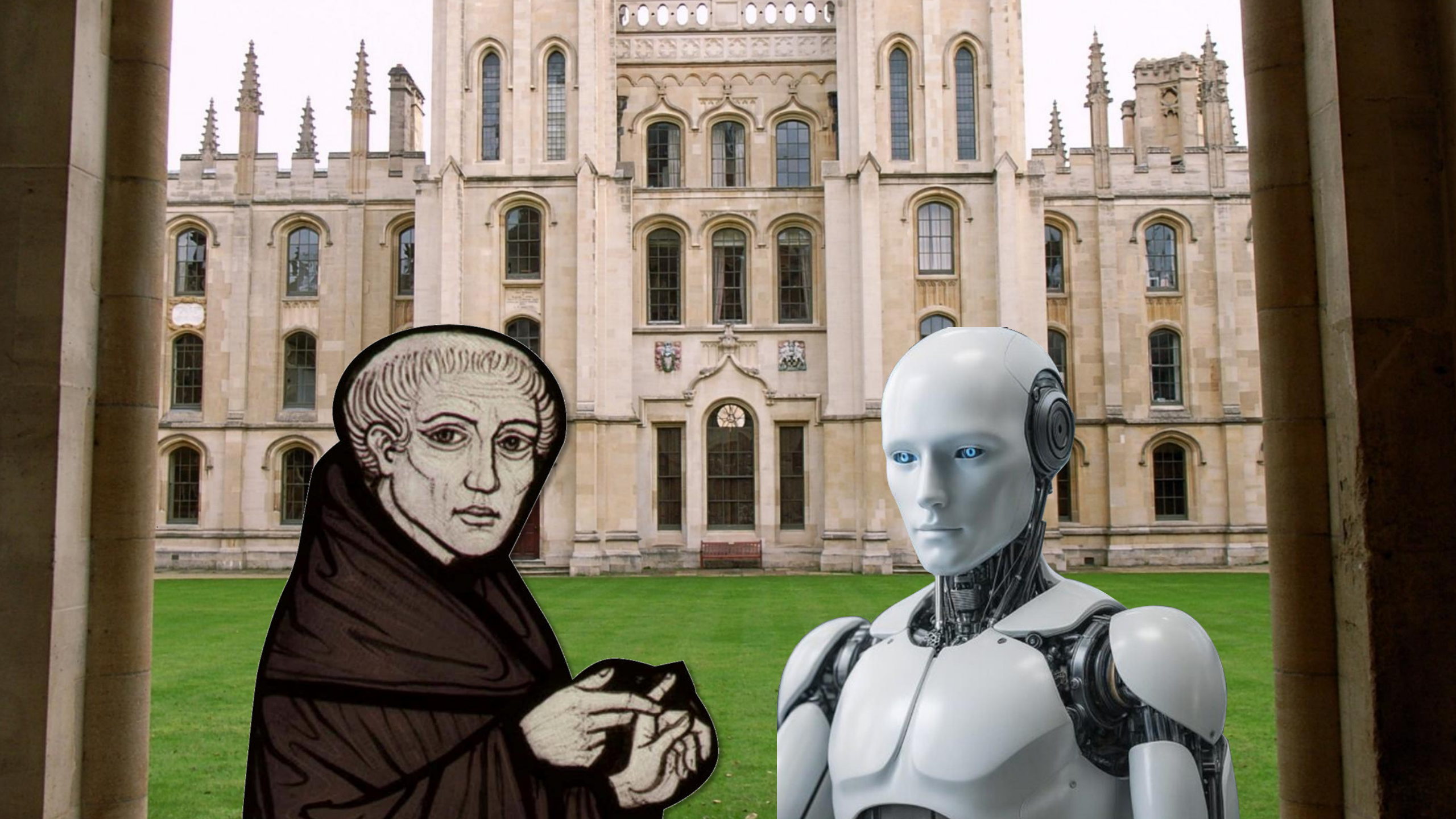
```
hclm: # household location choice model
inc_20_30,rent: # market segment
        ln_job_access_10min_sov:  0.001
        ln_job_access_30min_sov:  0.001
        ln_rent:                  0.001
        ln_unit:                  0.001
        prop_high_income:         0.001
        prop_low_income:          0.001
inc_20_30,own:

…
```

Calibrated Model Specification

```
hclm: # household location choice model
inc_20_30,rent: # market segment
        ln_job_access_10min_sov:  -0.2305
        ln_job_access_30min_sov:   0.8257
        ln_rent:                  -0.0961
        ln_unit:                   0.8860
        prop_high_income:         -3.5290
        prop_low_income:           0.1627
inc_20_30,own:

...
```



Proposal: Testing Hypotheses with Differentiable UrbanSim

Conjecture:

If $\dim\left(\widehat{\boldsymbol{\theta}}_{\text{null}}\right) = k$,

$\dim\left(\widehat{\boldsymbol{\theta}}_{\text{extended}}\right) = k + q$,

$\dim(L) = n \to \infty$, and

errors independent with constant variance over zones

Then CLT & null imply

$$\frac{L\left(\widehat{\boldsymbol{\theta}}_{\text{null}}\right) - L\left(\widehat{\boldsymbol{\theta}}_{\text{extended}}\right)}{L\left(\widehat{\boldsymbol{\theta}}_{\text{extended}}\right)/(n-k-q)} \to \chi^2(q)$$

Proposal: Testing Hypotheses with Differentiable UrbanSim

Example:

$\dim(\hat{\boldsymbol{\theta}}_{\text{null}})=186$

$\dim(\hat{\boldsymbol{\theta}}_{\text{extended}})=186+2$ ← In residential development model, Wash. State indicators—own & rent

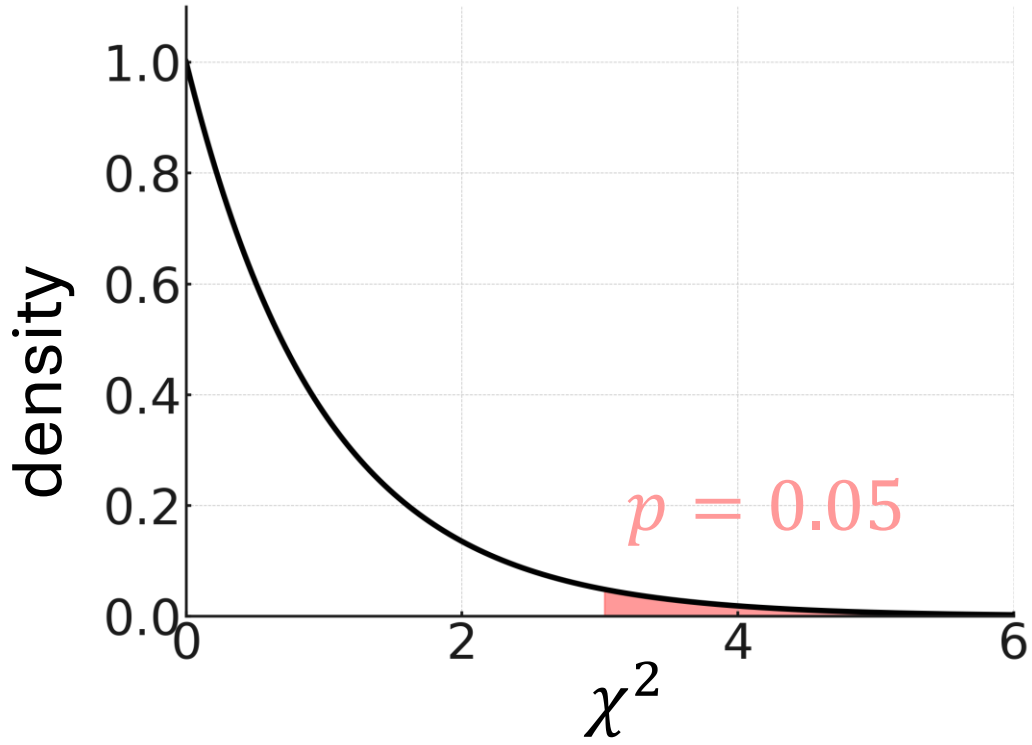
$\dim(L)=13770$

$\hat{\theta}_{\text{state53,own}} = ?$

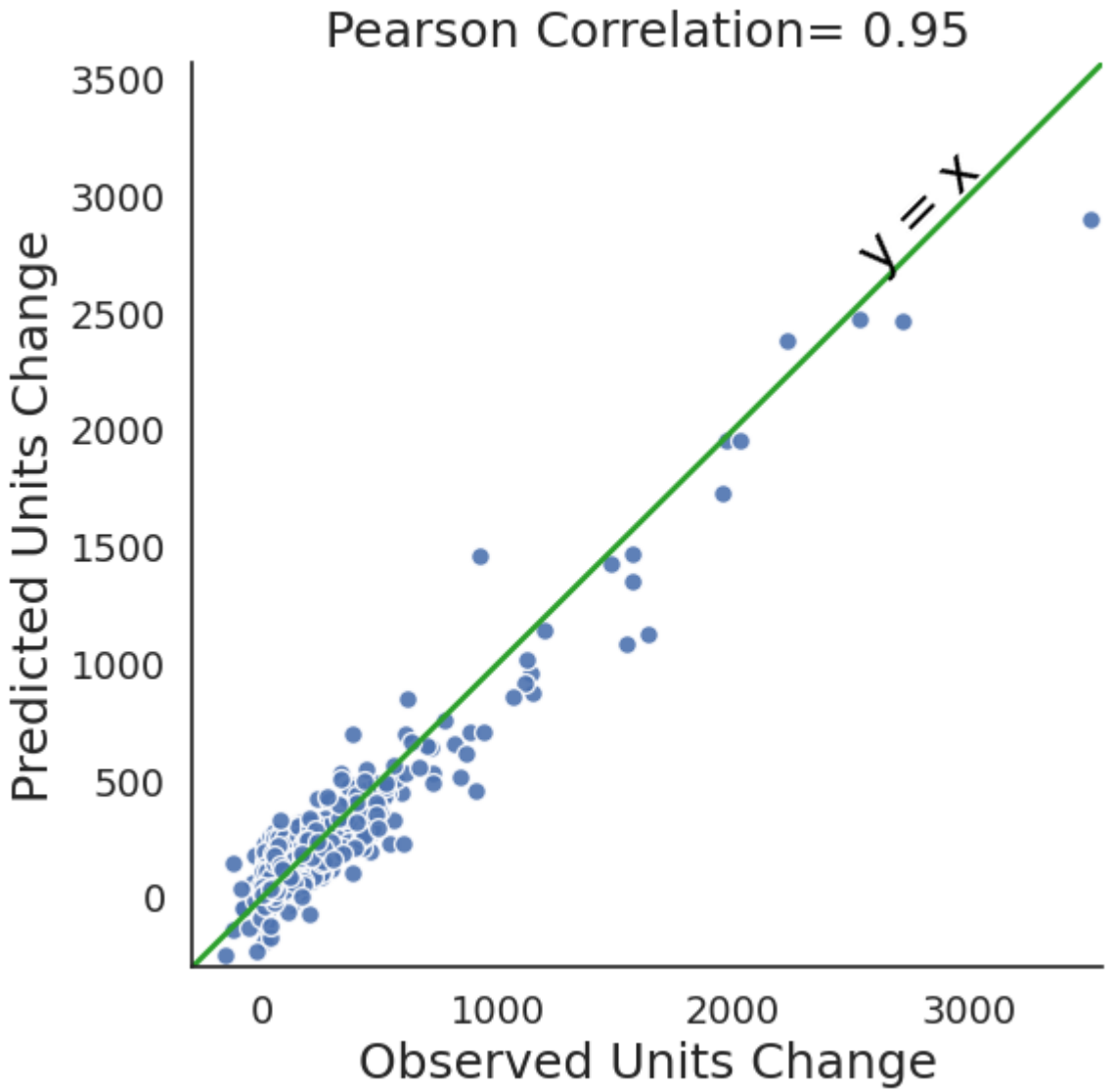
$\hat{\theta}_{\text{state53,rent}} = ?$

$\chi^2 = 6.00$ on 2 d.f.

$p = 0.05$



Change in Housing Units by Tract, 2010-2020



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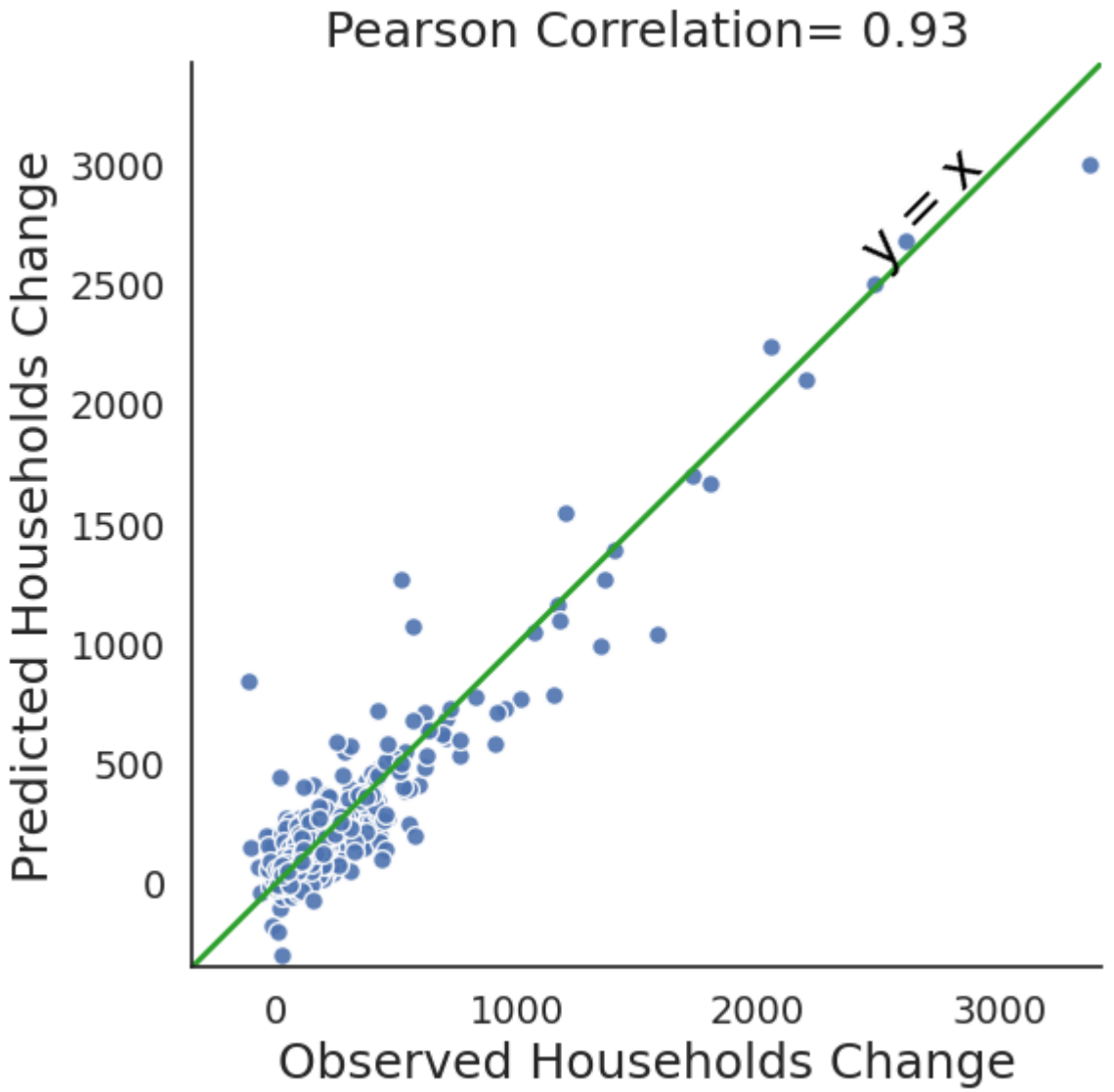
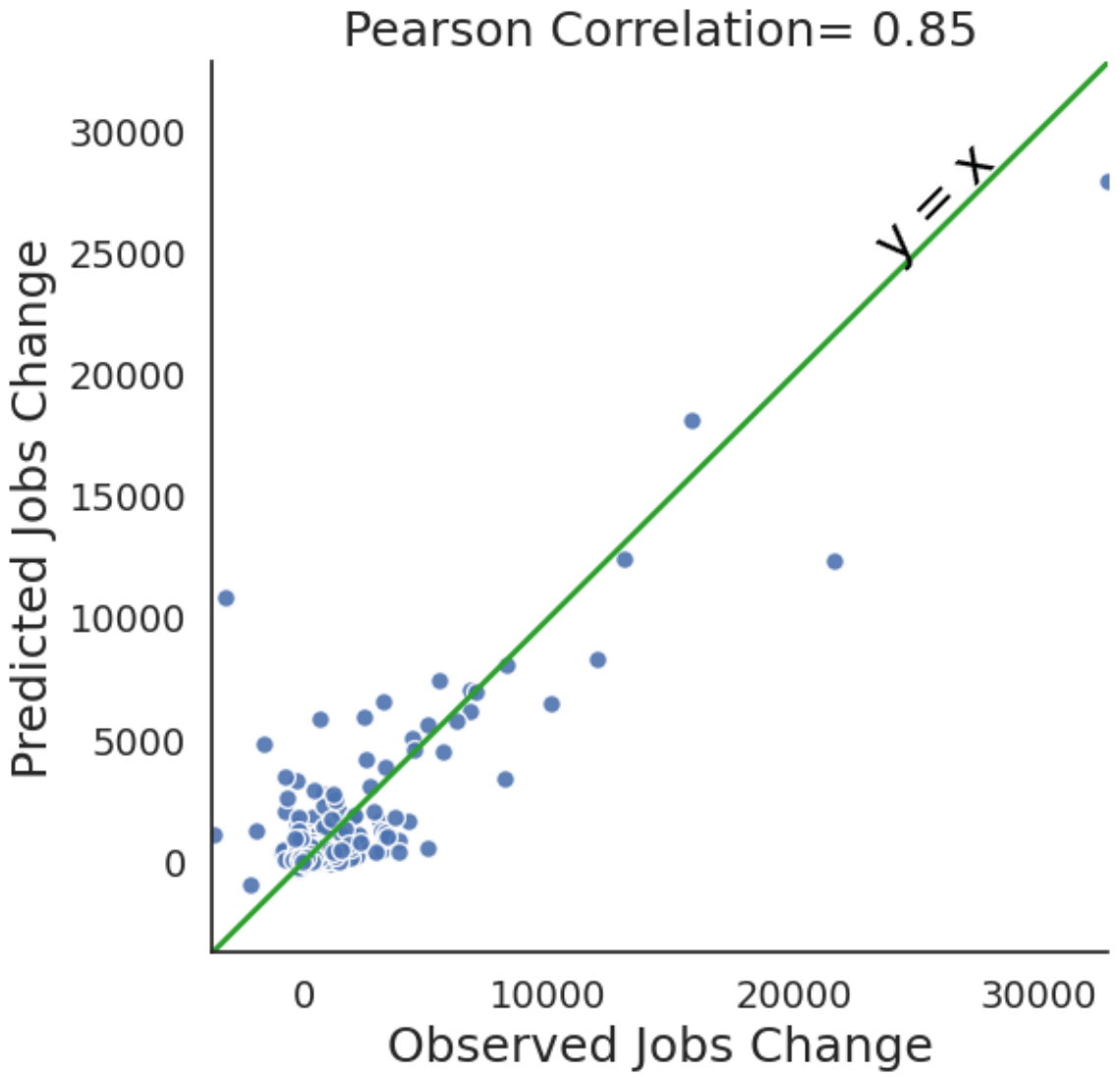
Change in Households by Tract, 2010-2020



DRAFT

Change in Employment by Tract, 2010-2020



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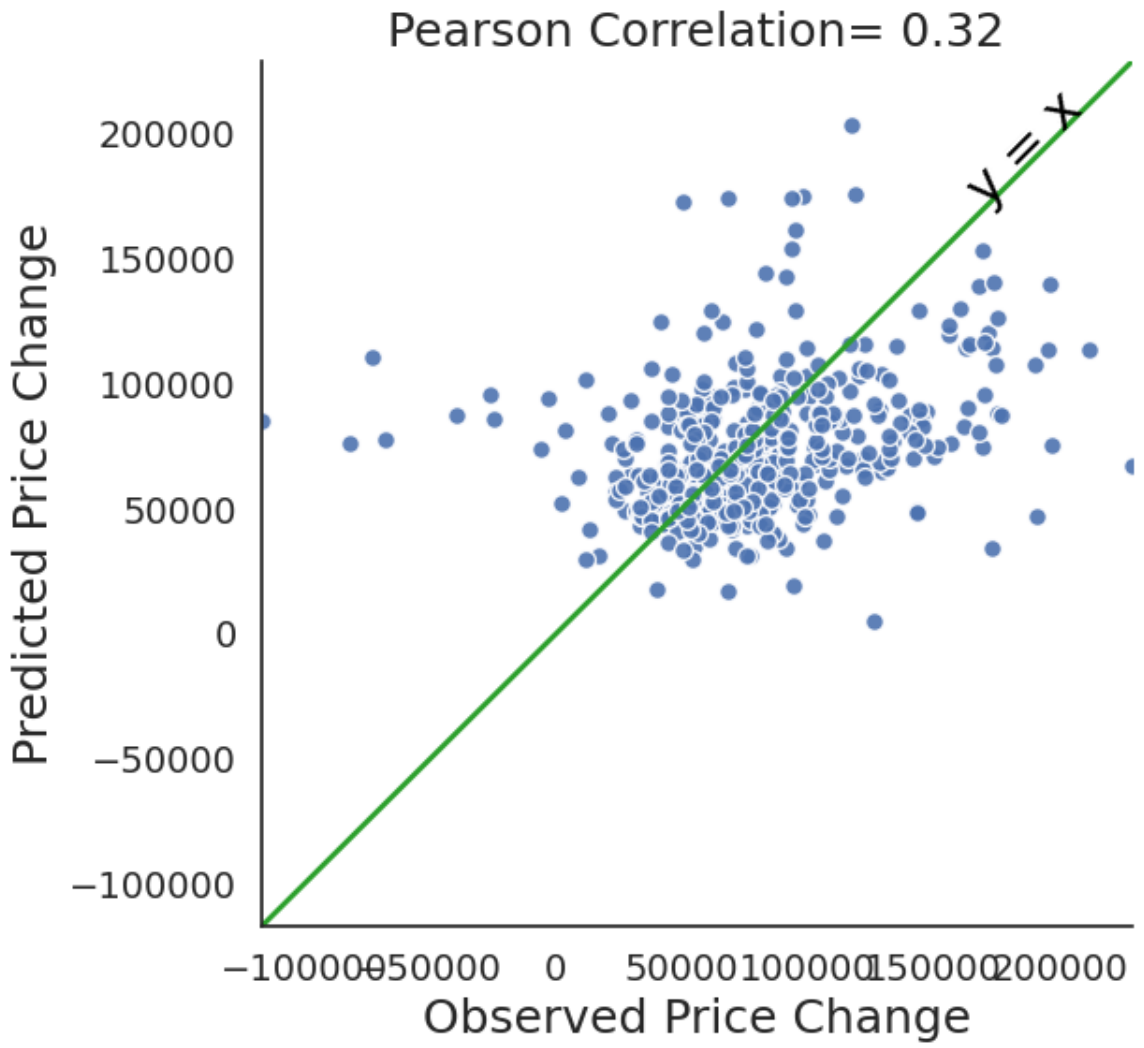
Change in Price by Tract, 2010-2020



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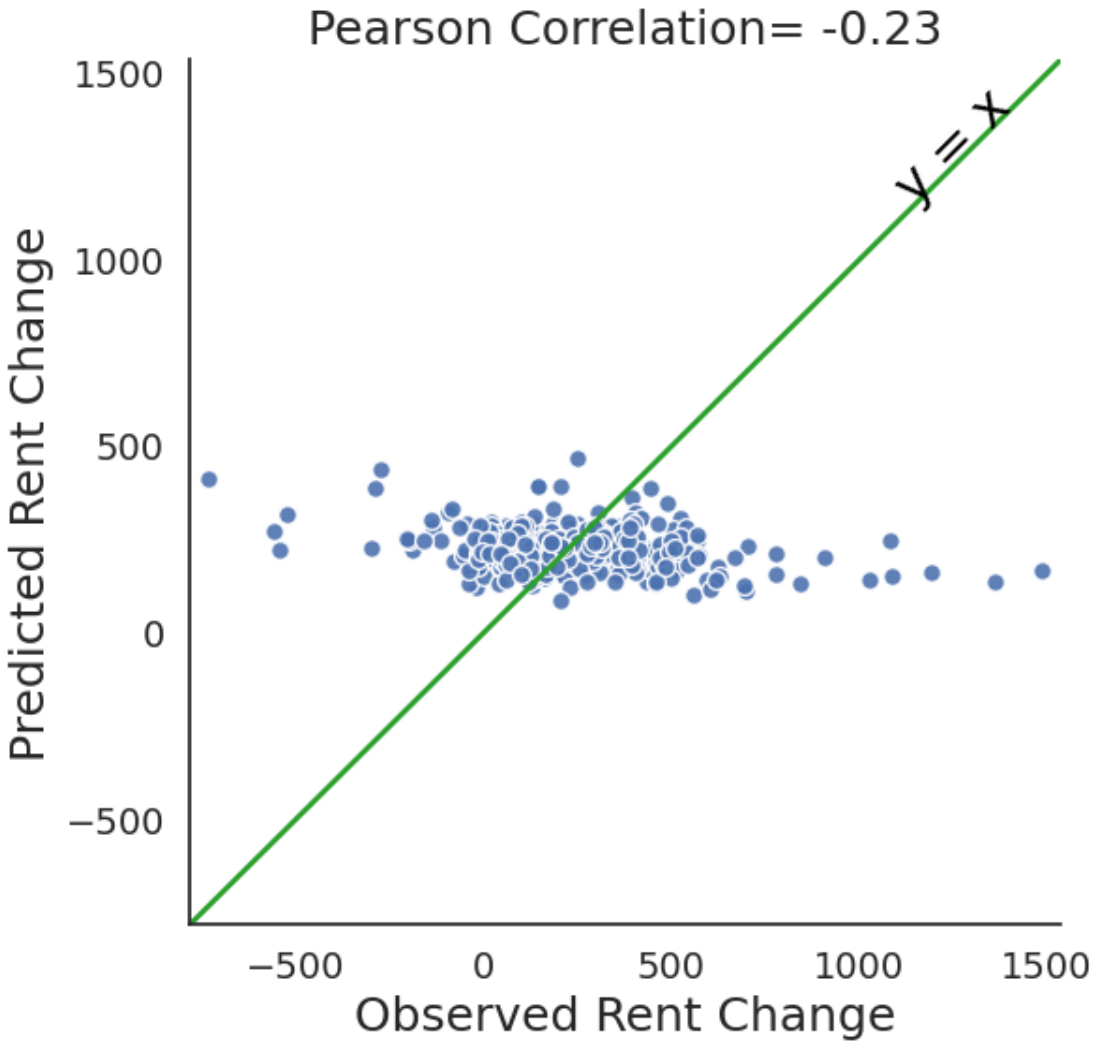
Change in Rent by Tract, 2010-2020



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Other Improvements, 2024–2025

🔧 Features	📊 Training	🏙️ Data
User-defined variables	NaN avoidance refactoring	*Pro Forma* capacity estimates
Parameter sharing & constraints	Convergence criteria	Historical UGB

Goals & Wish List: 2025–2026

💰 Outputs	🧪 Validation	🏛️ Forecast
Better price & rent prediction	Hessian PSD?	Finalize specs
Block & block group analysis	Robust to initialization?	Jurisdictional review
		Council adoption

THANK YOU!!!

Metro

Bryan Blanc
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Jake Lovell
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Bentley PTV BLS United States Census

And more!

Questions?

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Metro

Arts and events
Garbage and recycling
Land and transportation
Oregon Zoo
Parks and nature

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