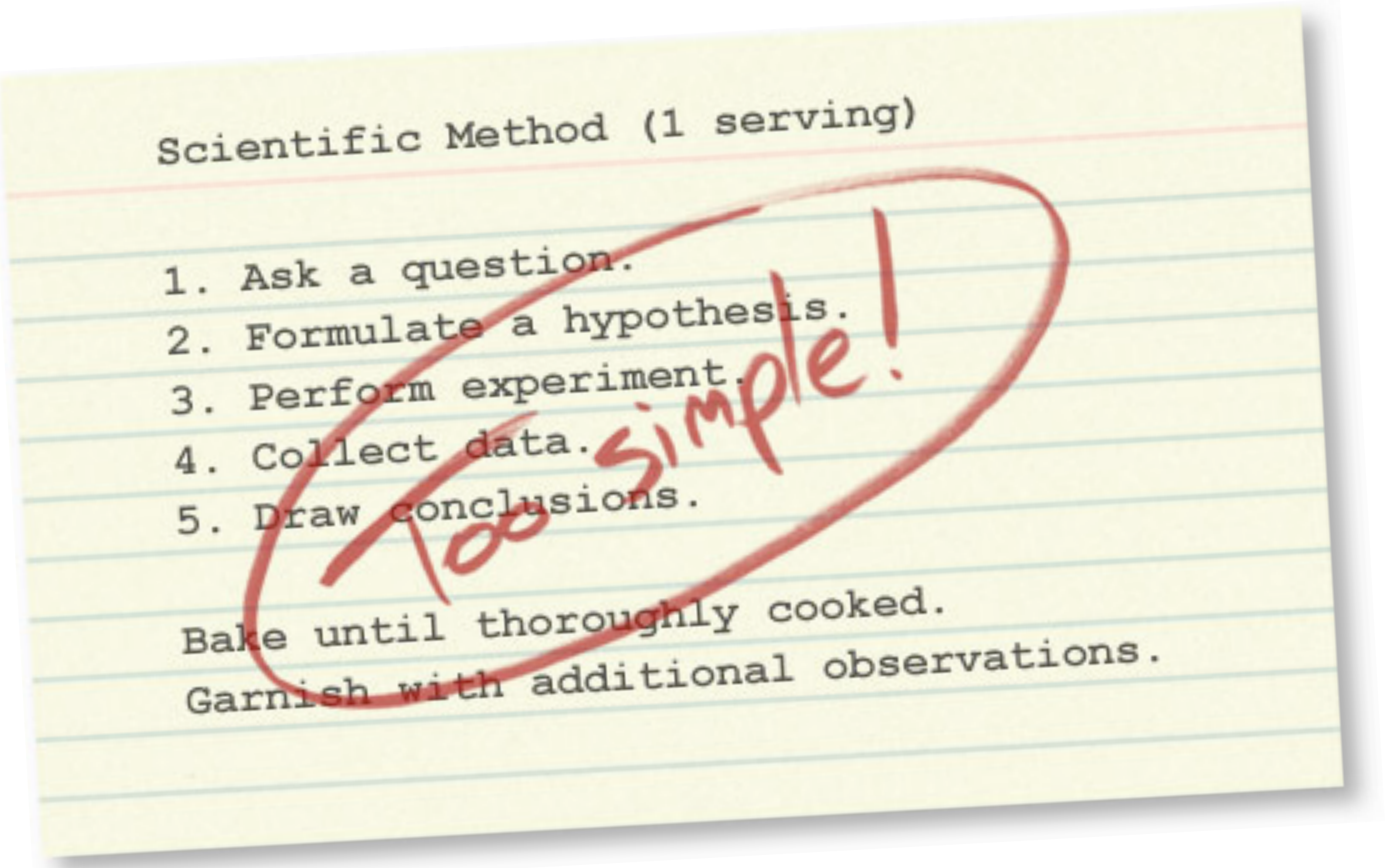
Predictive Models of Development Teams

and the Systems They Build

Robert Smallshire

@robsmallshire


Scientific Method (1 serving)
1. Ask a question.
2. Formulate a hypothesis.
3. Perform experiment.
4. Collect data.
5. Draw conclusions.
Bake until thoroughly cooked.
Garnish with additional observations.
Too simple!

Experimental Science

Randomised controlled trials

- Developers don't like to be watched
- Eliminating extraneous factors
- Toy problems aren't realistic
- No two projects are the same
- Can't do double-blind
- Students have little experience
- Time and money

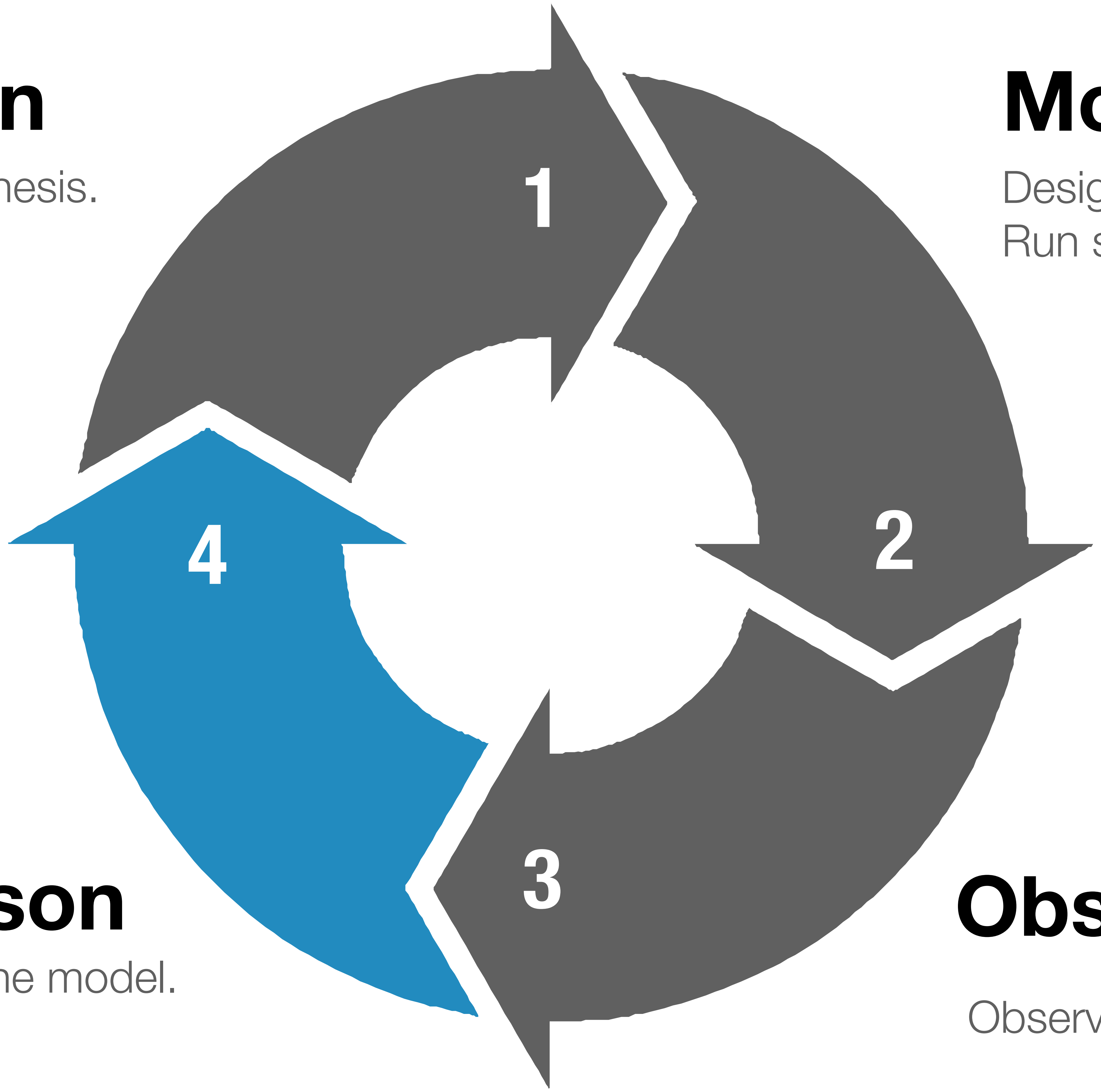
How can we know?

Prediction

Formulate a hypothesis.

Modelling

Design a conceptual model.
Run simulations.



Comparison

Validate or refute the model.

Observation

Observe and record reality.

Modelling system growth 1
How many people work on your system?

Predicting project progress 2
How many people should work on your system?

Software process dynamics 3
How can you construct models and run simulations?

Lifetimes in the software industry

Systems and their architectures are long lived

Sources: Software Lifetime and its Evolution Process over Generations, CEO Succession Practices: 2012 Edition, Investors Chronicle,

Simulating Developer Productivity

Draw teams at random from a productivity distribution

Productivity on 10000 SLOC codebase

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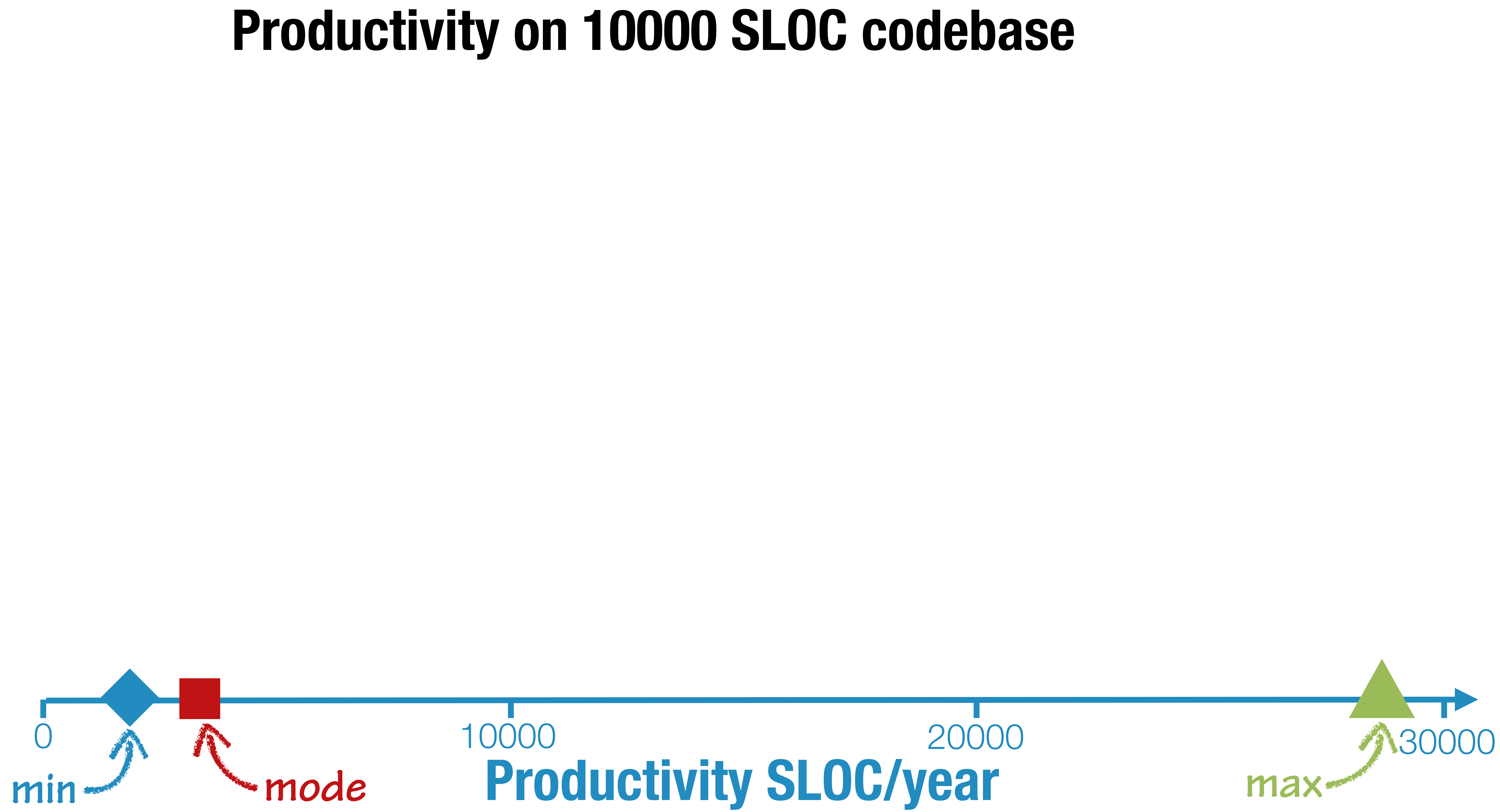

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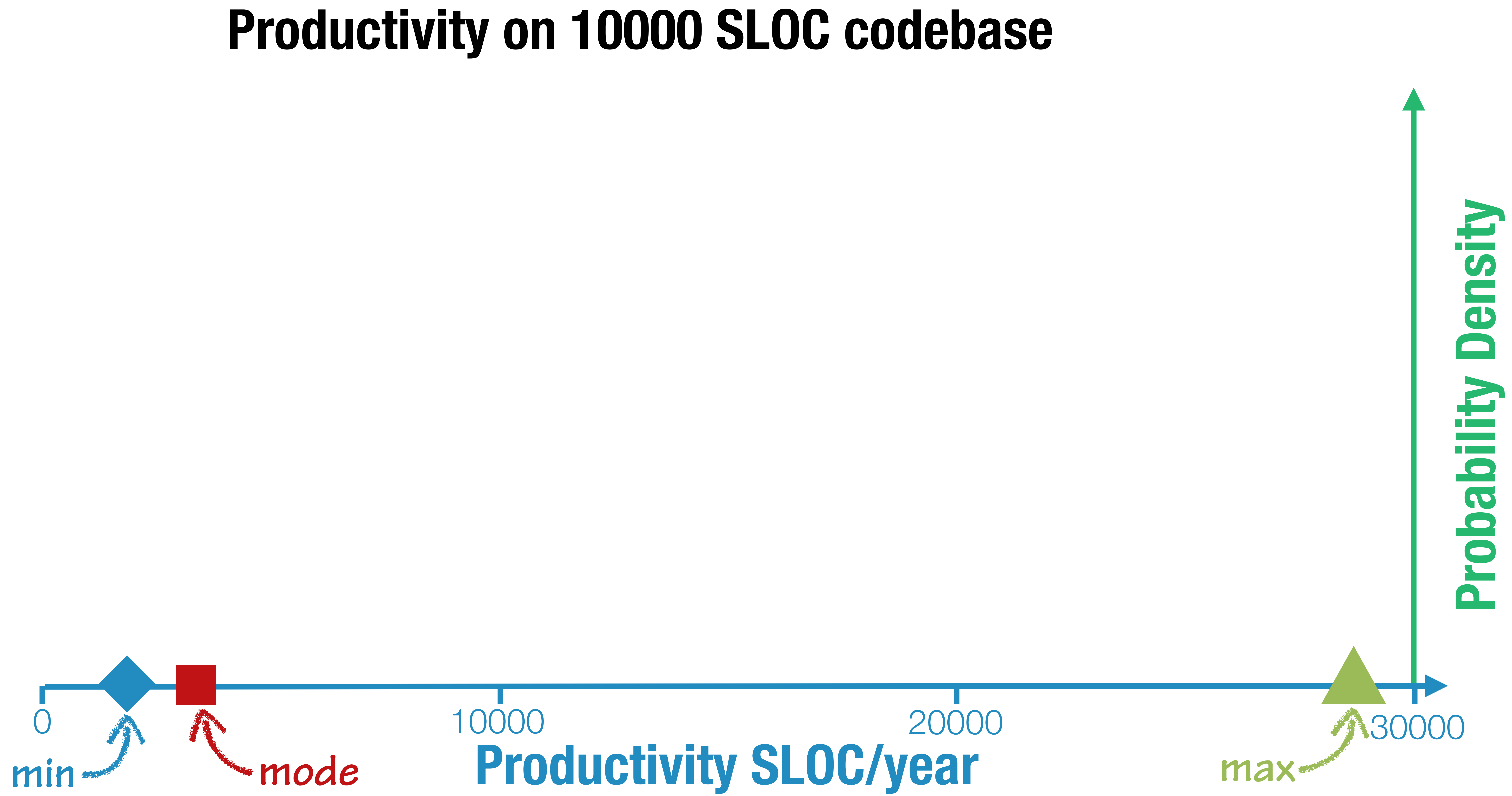

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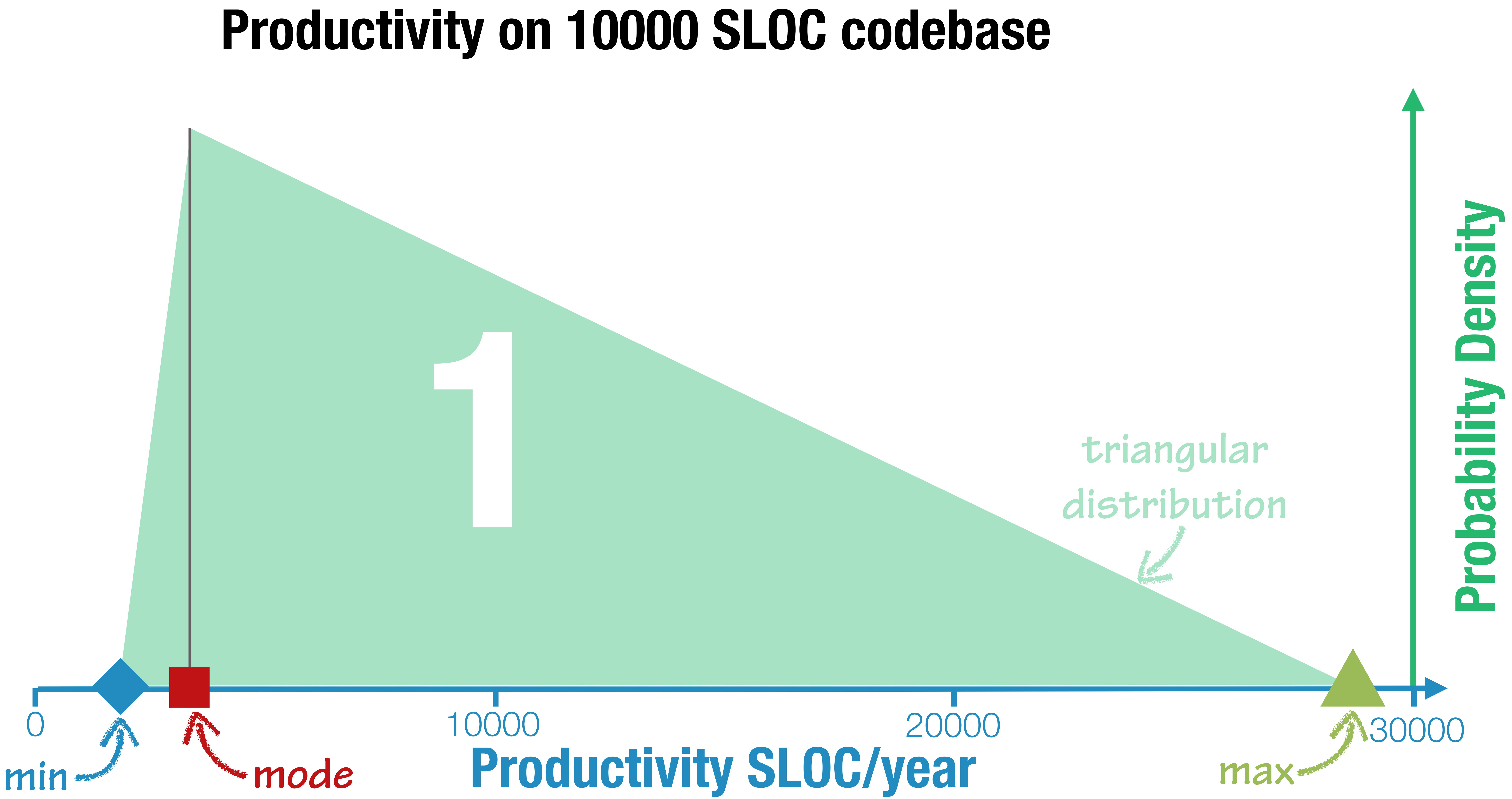

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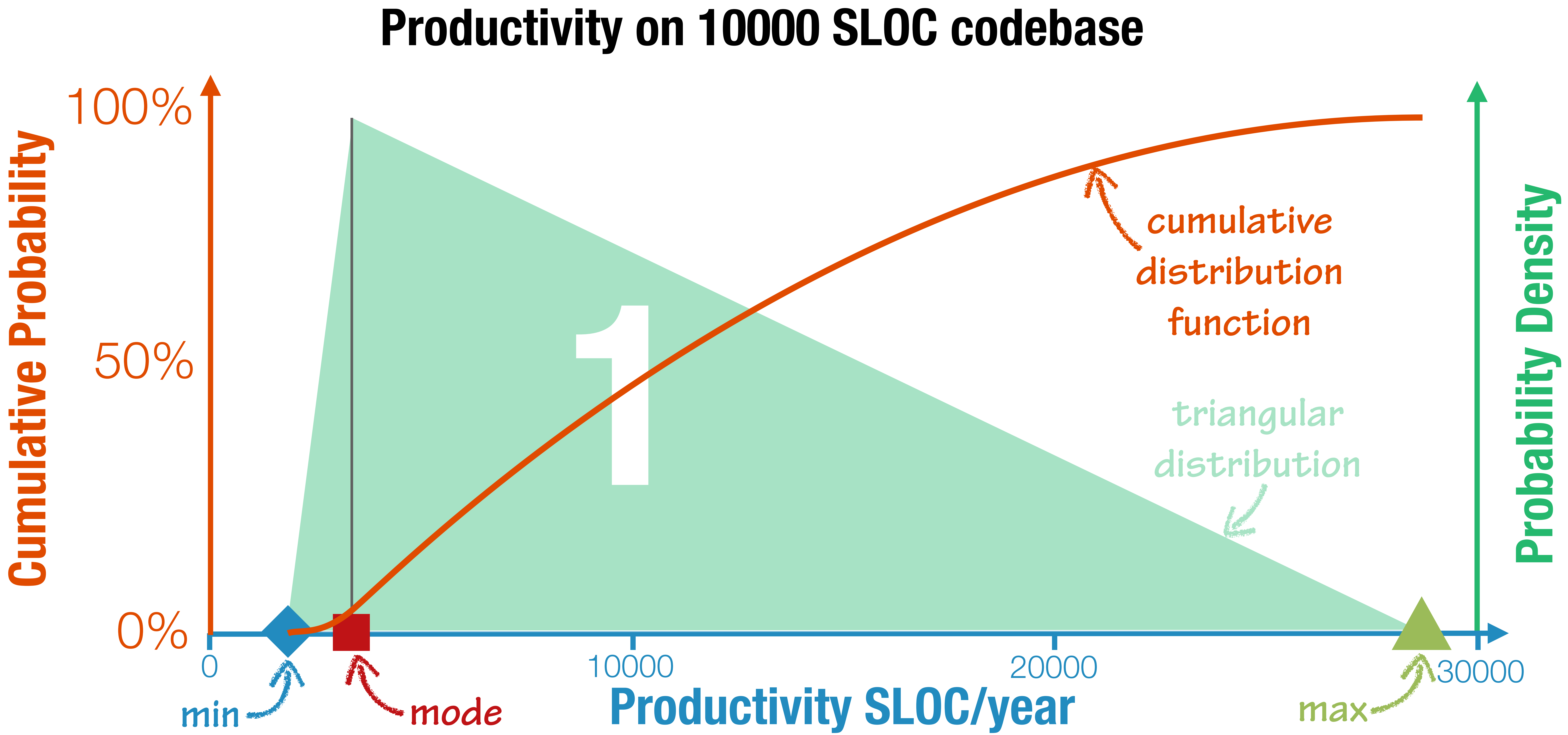

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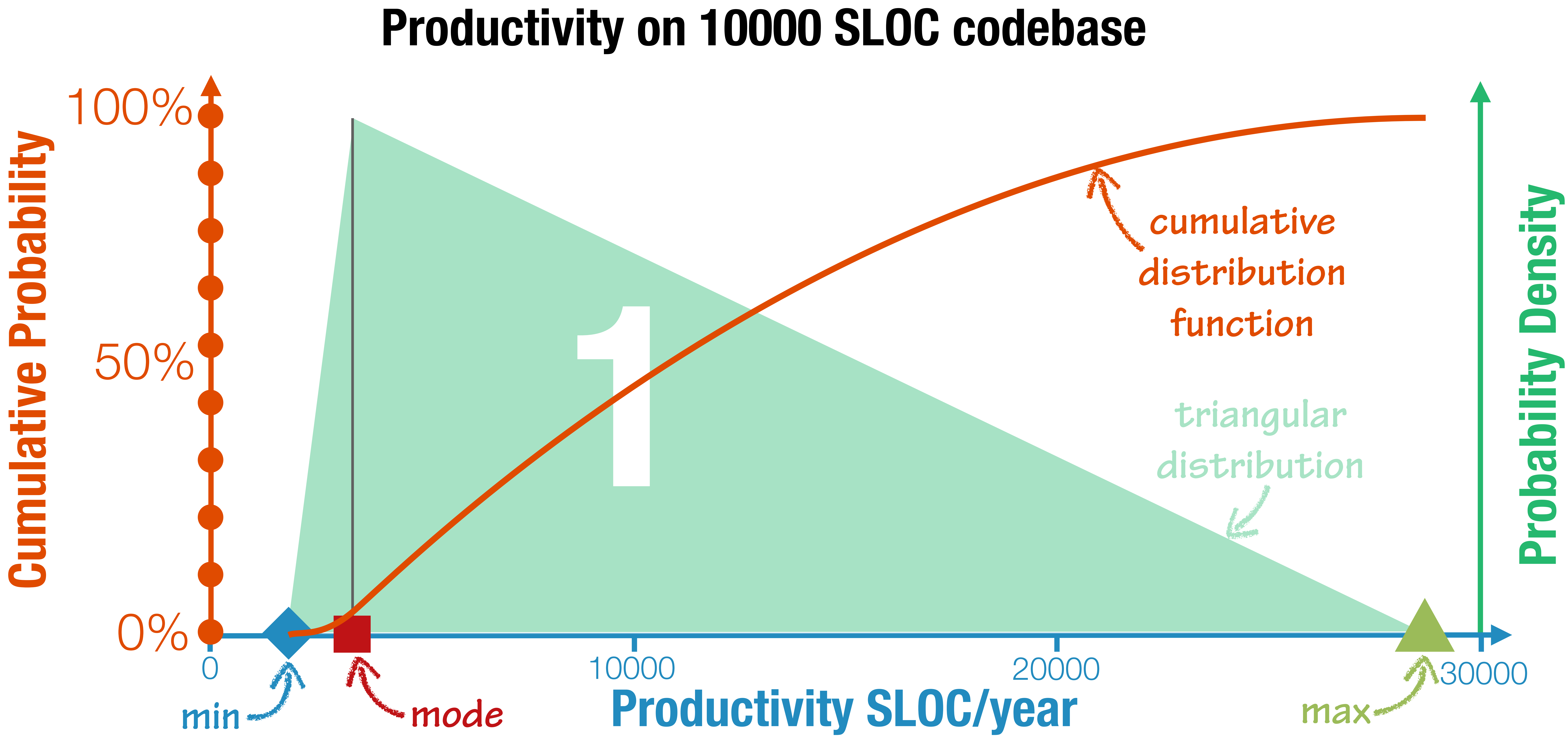

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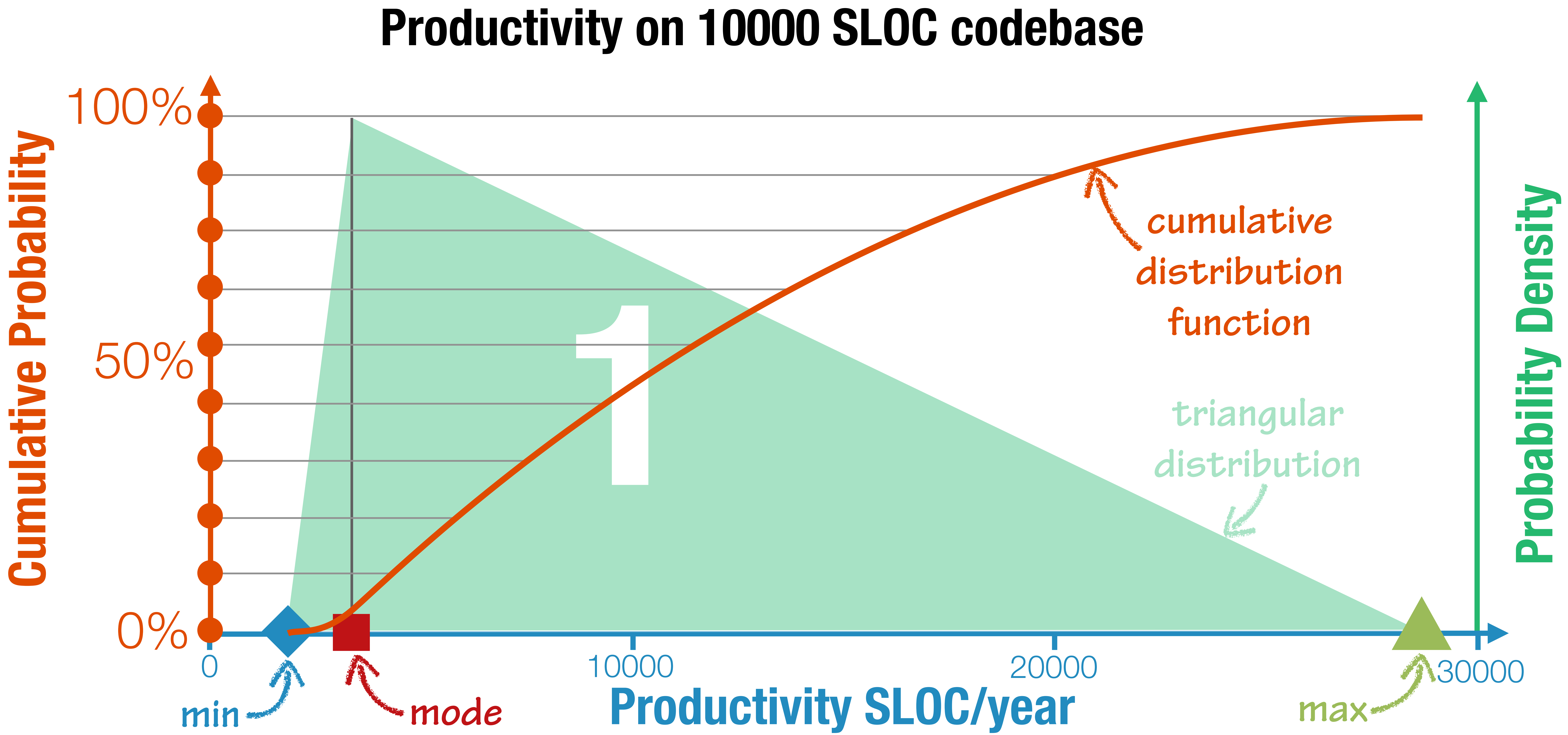

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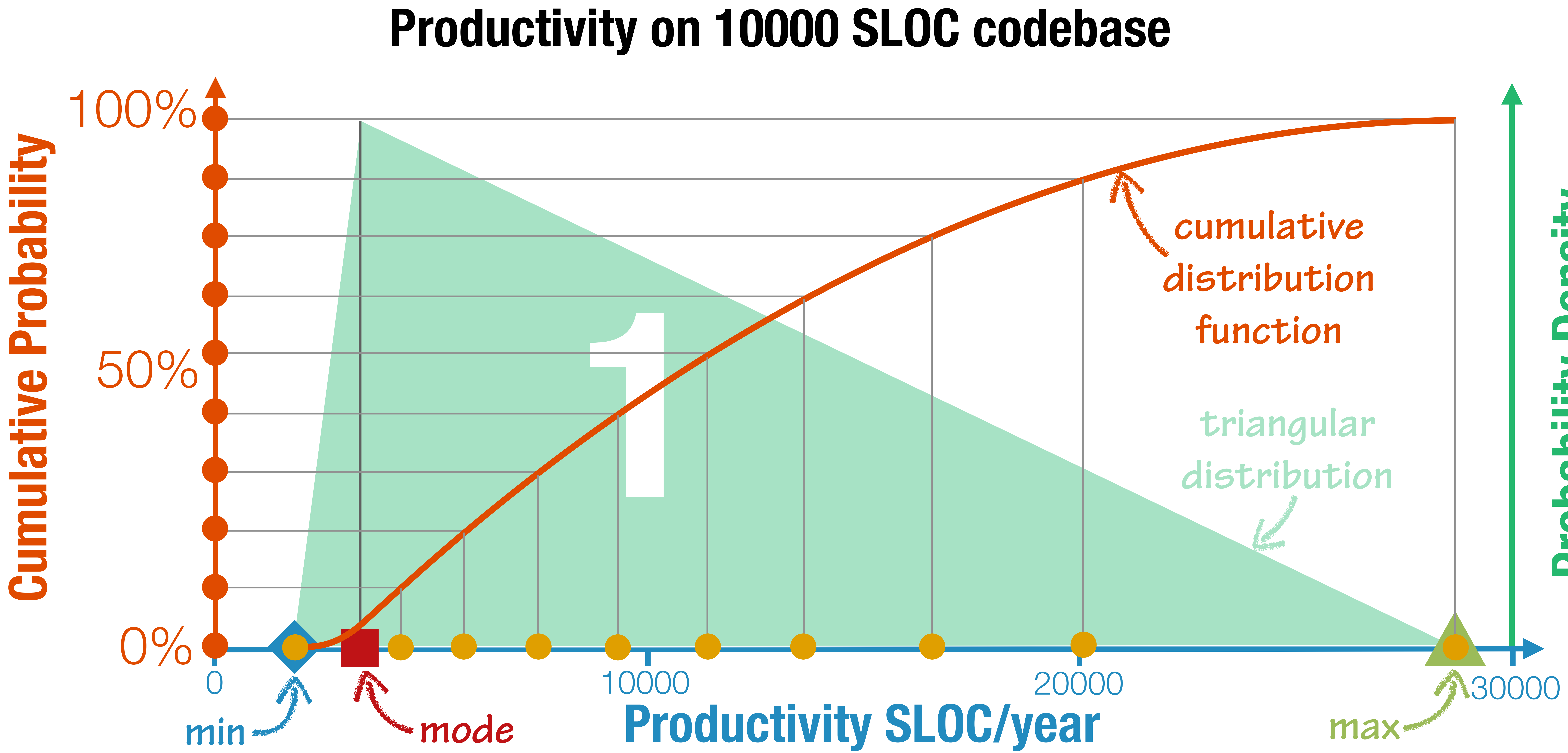
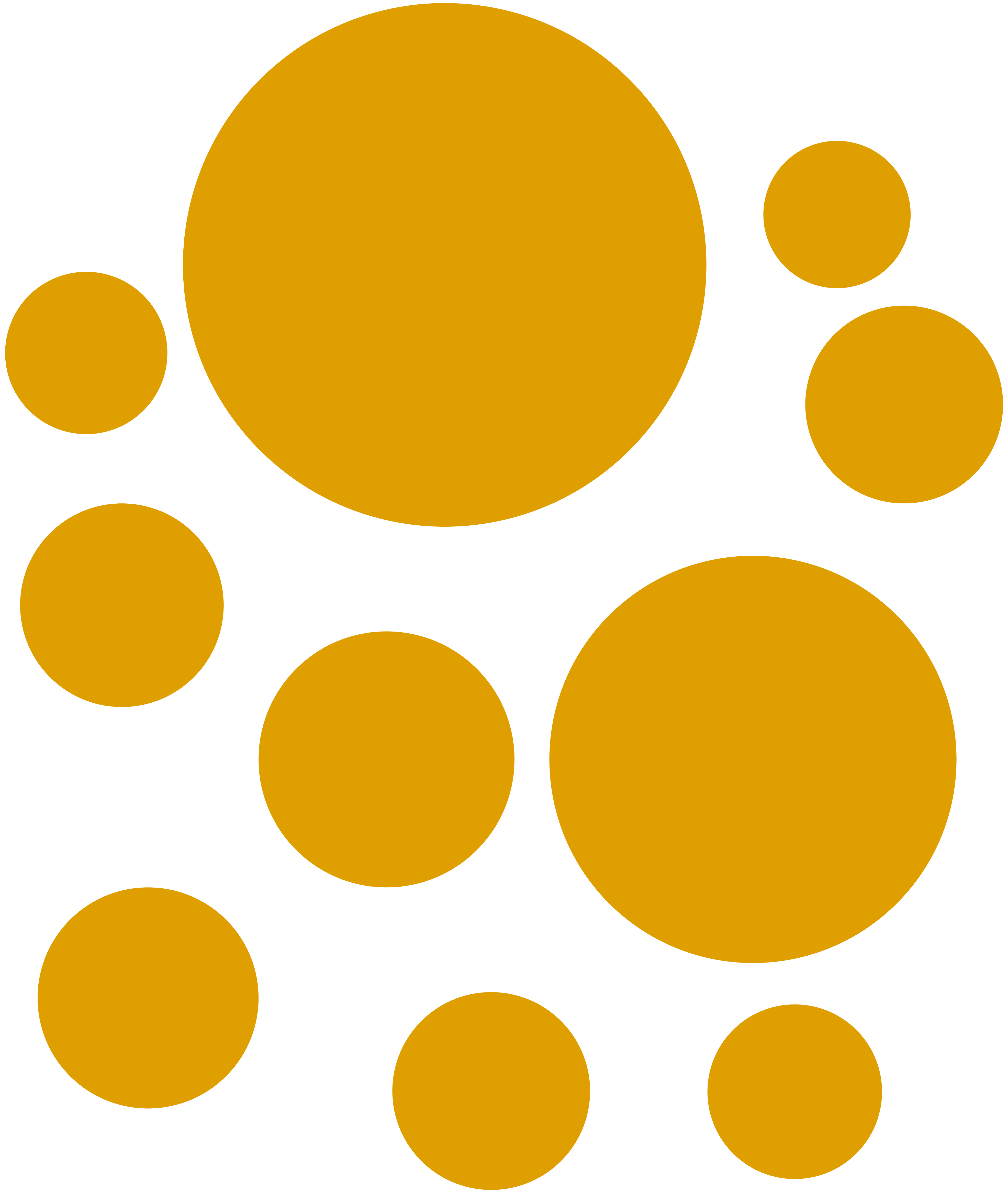
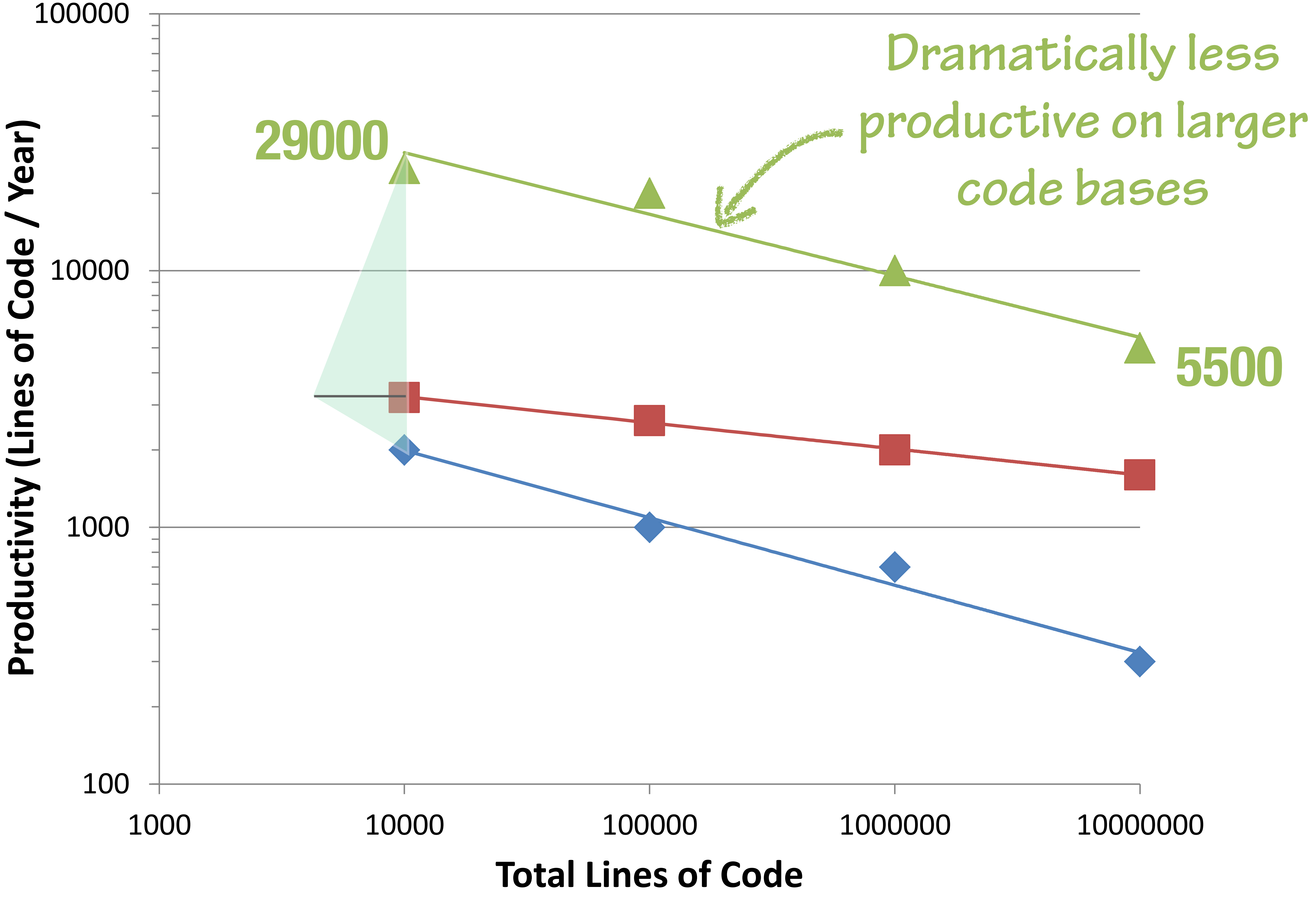




Modelling team and code evolution

Use published productivity data to forward model code size.

At any given system size we can predict a distribution for developer productivity.



Sources: COCOMO II

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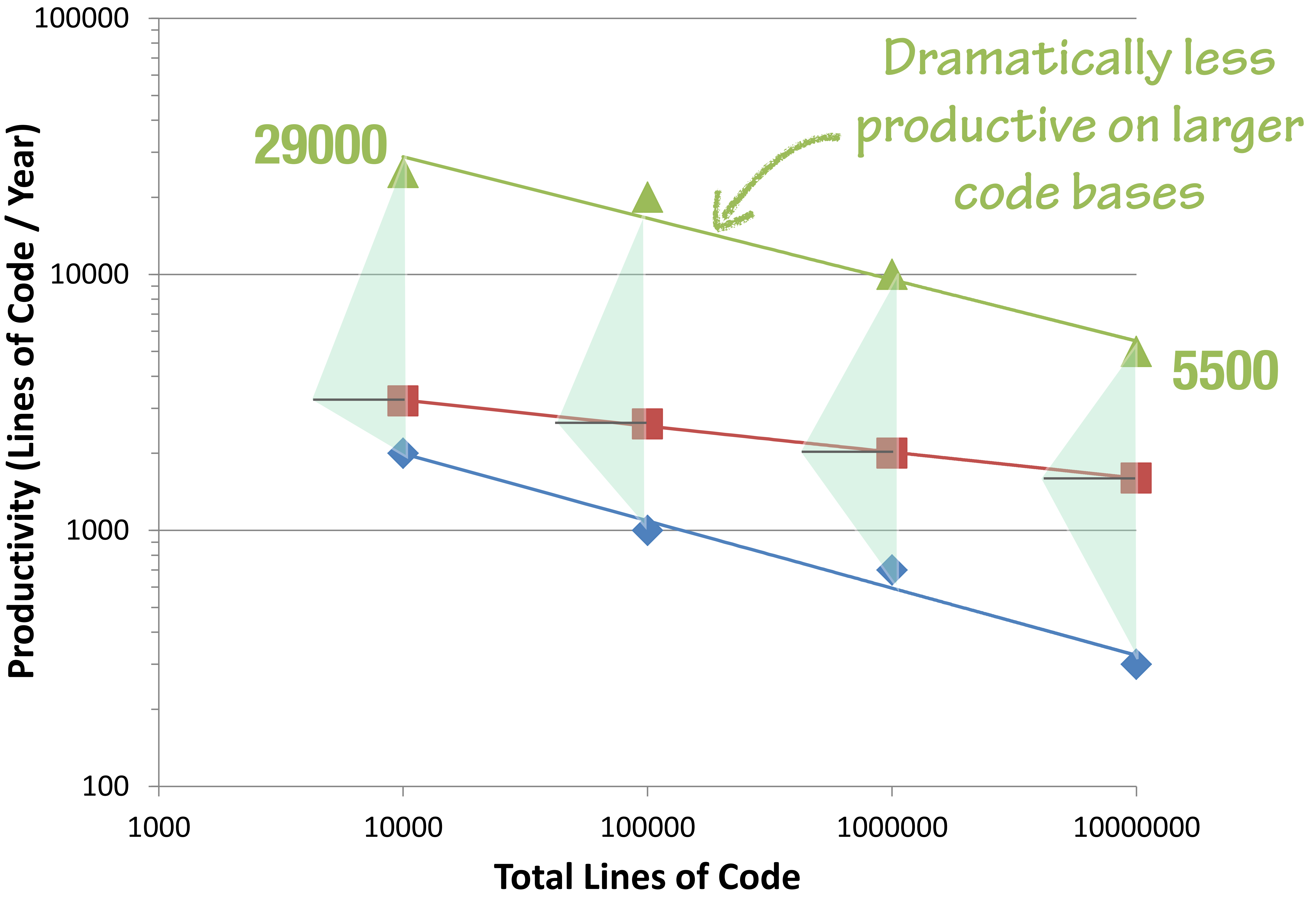

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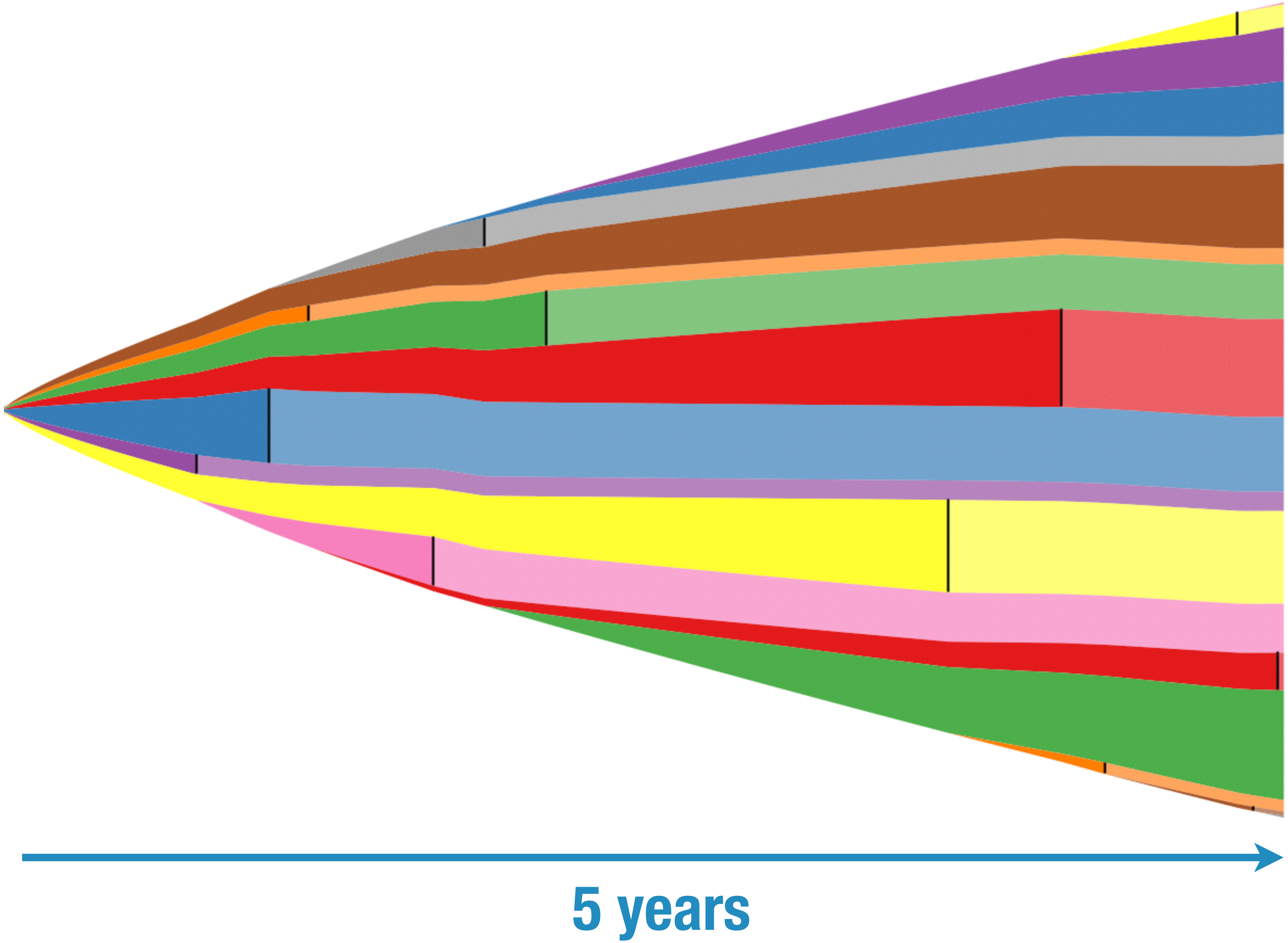
Simulating a team of seven over five years

5 years

Simulating a team of seven over five years



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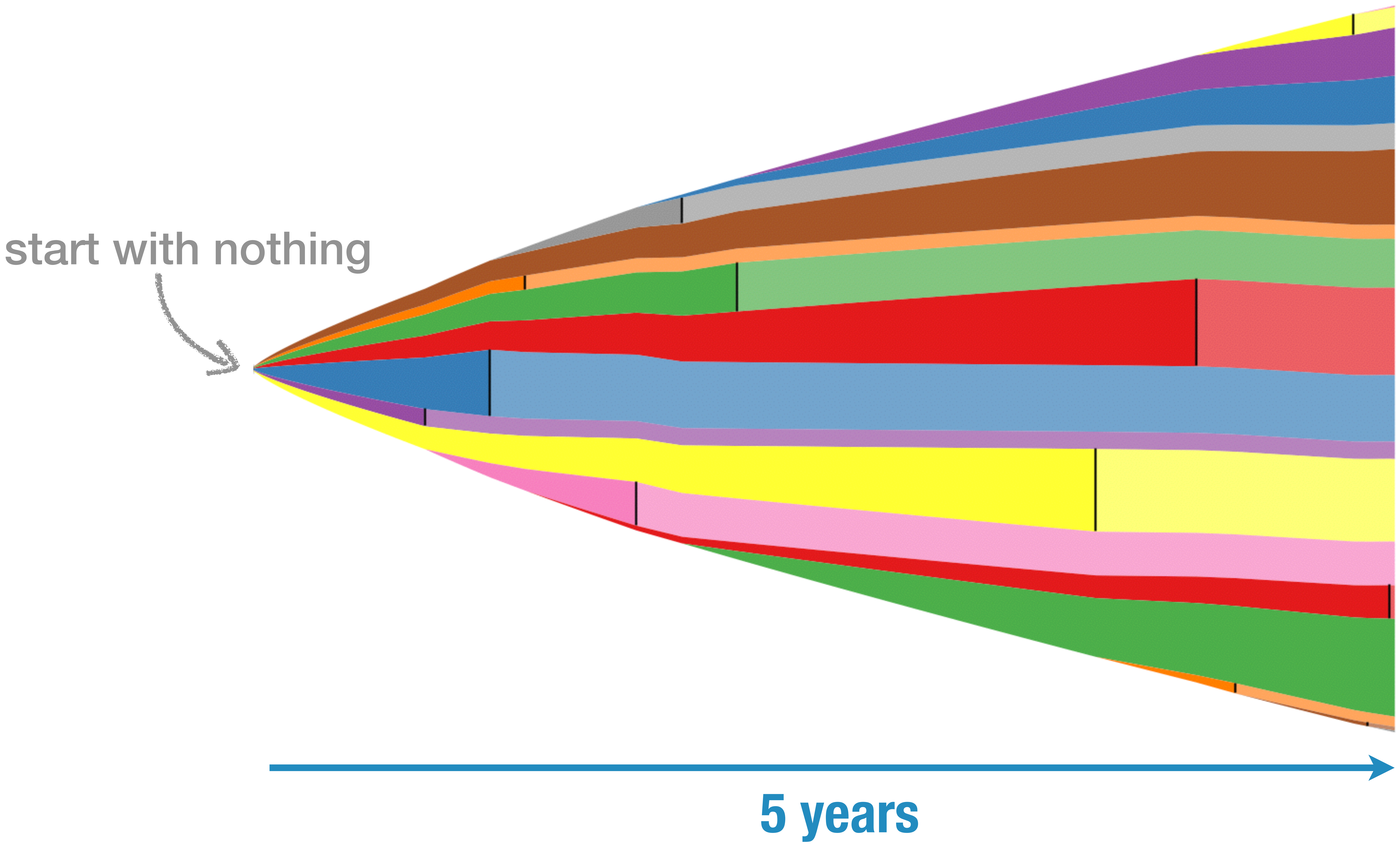

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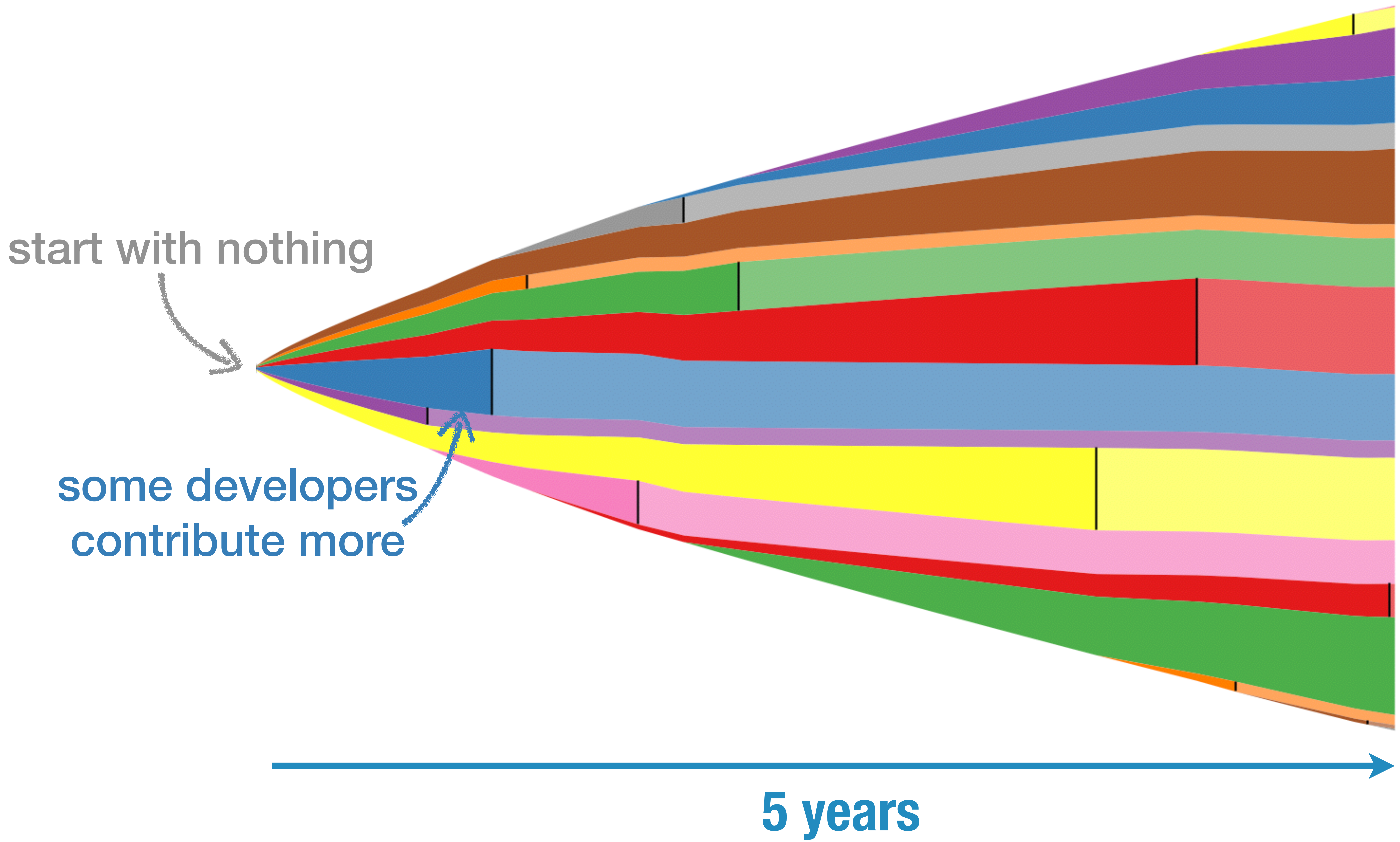

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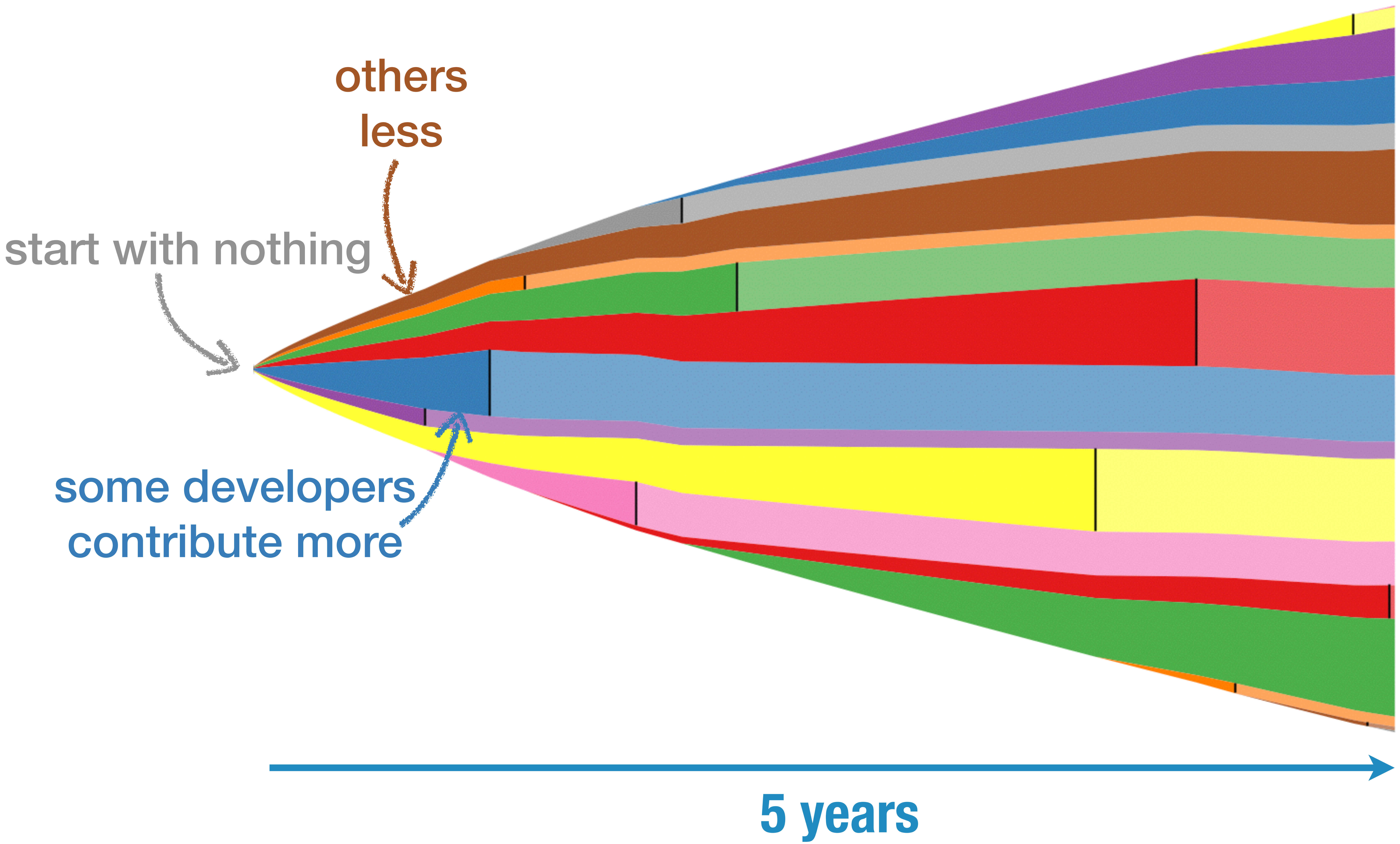

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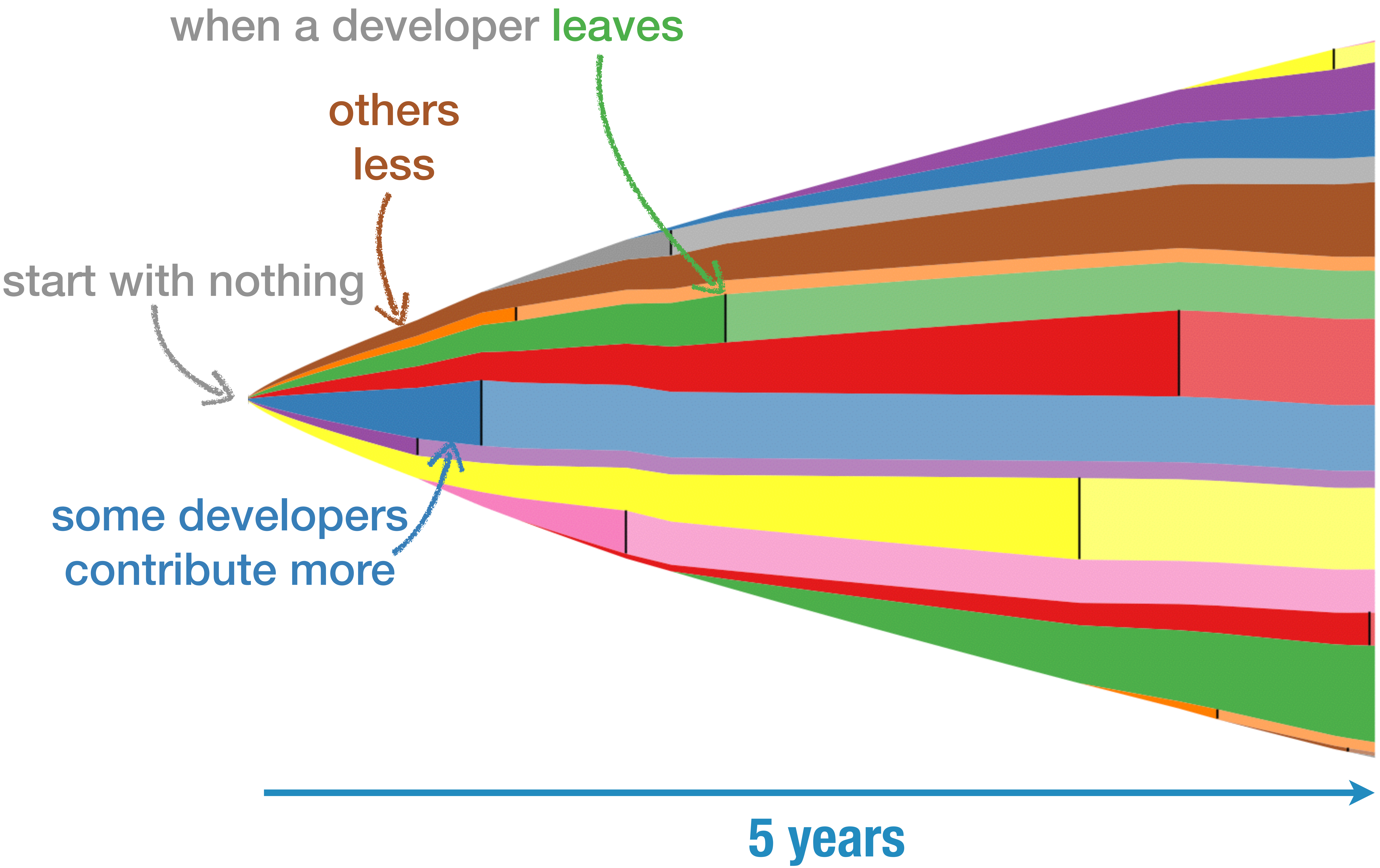

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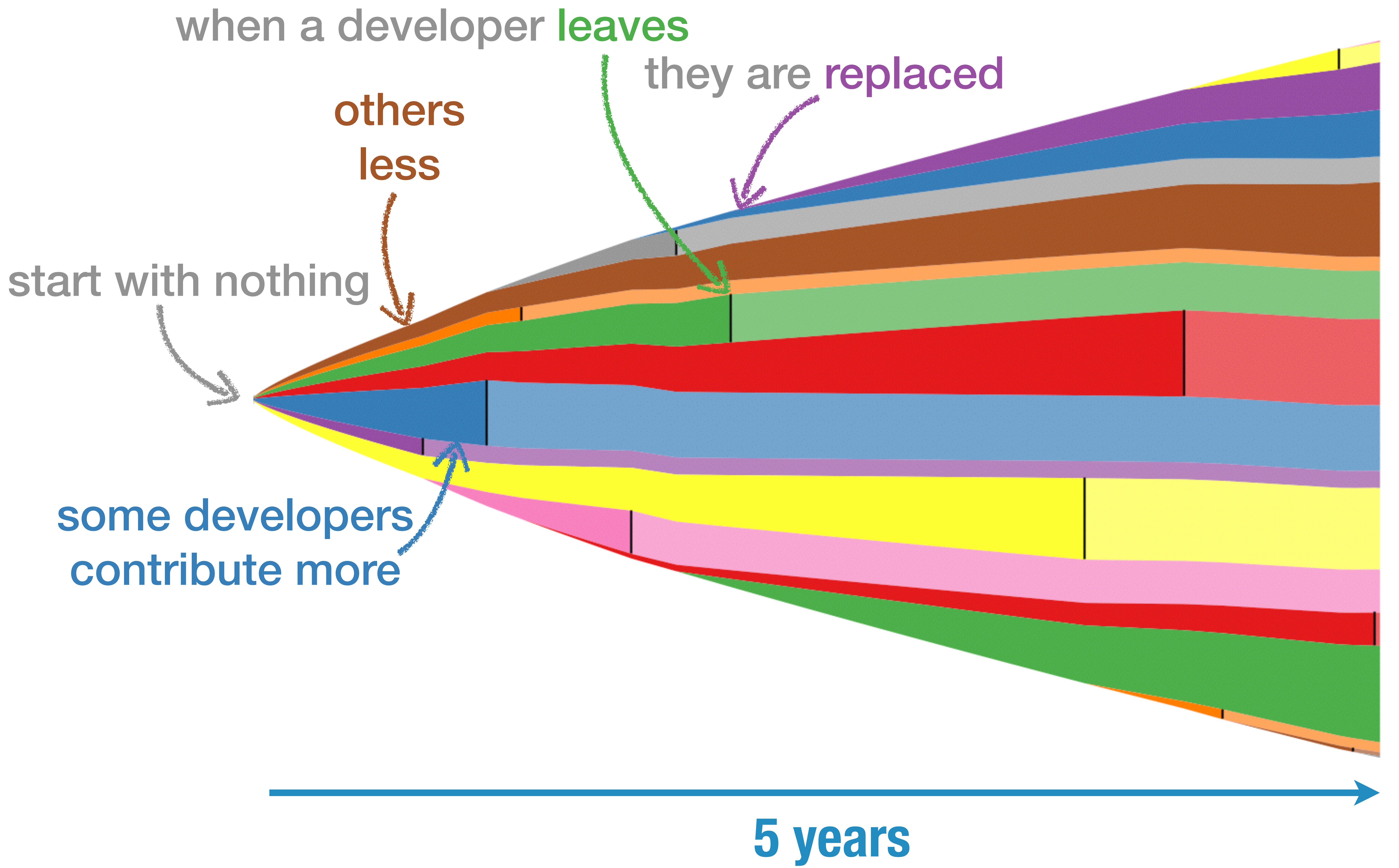

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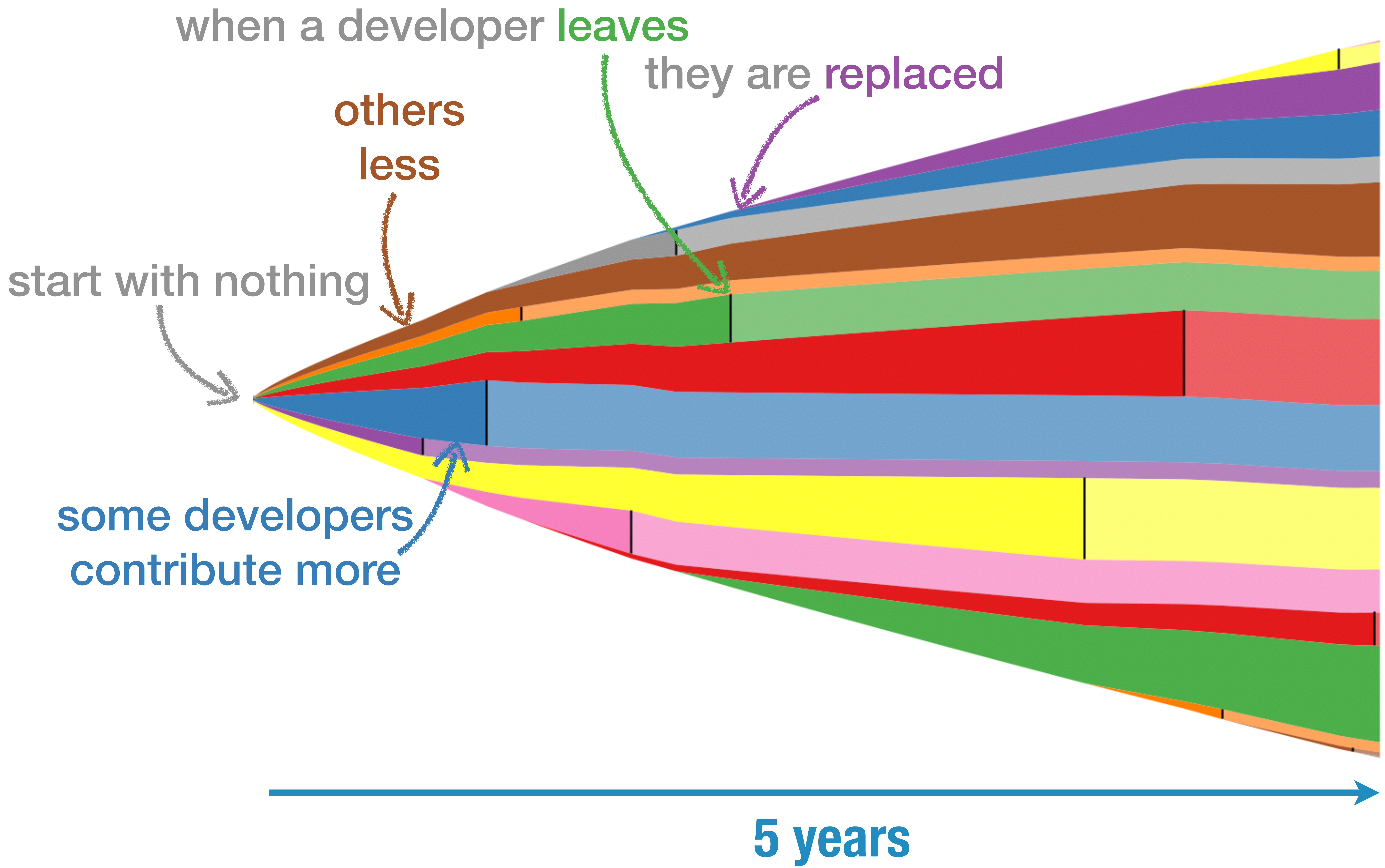

After 5 years we have 235 k lines of code written by a total of 19 people.

Only 37% of the code is by current team


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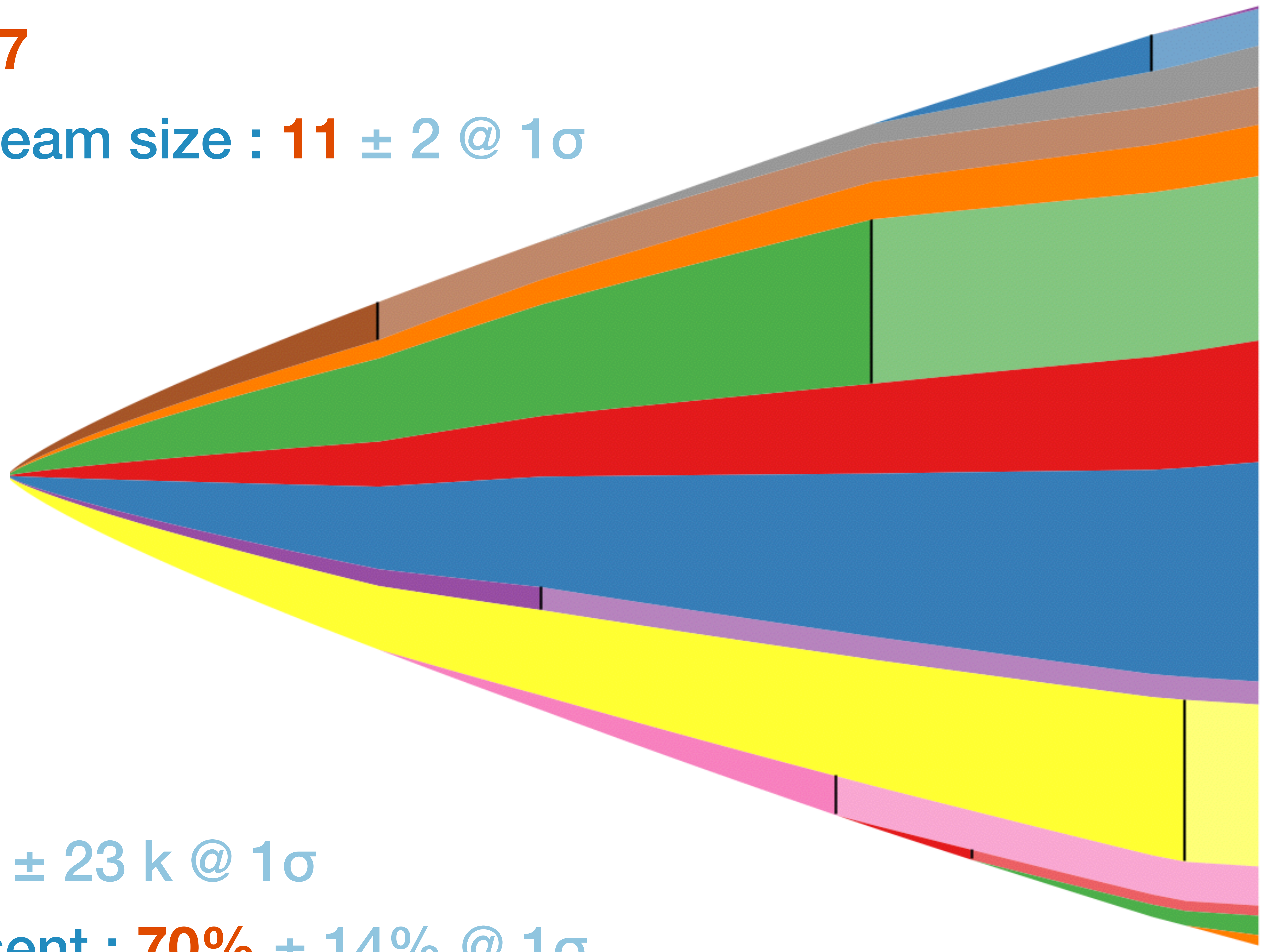
3 years

Team Size : **7**

3 years

Team Size : 7

Cumulative team size : 11 ± 2 @ 1σ



157 kLoC

LoC : 157 k ± 23 k @ 1σ

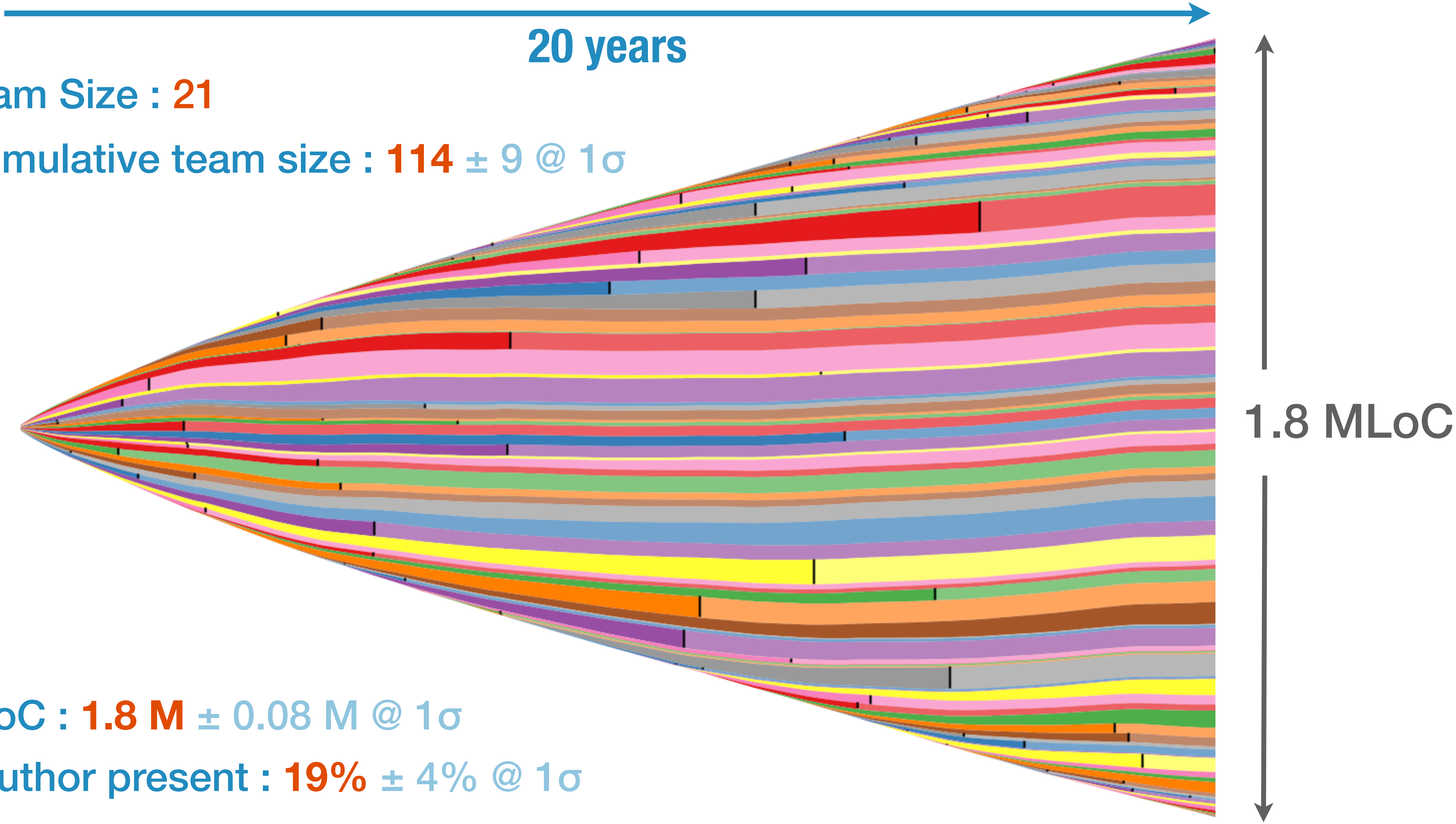
Author present : 70% ± 14% @ 1σ

20 years

Team Size : 21

Team Size : 21

Cumulative team size : 114 ± 9 @ 1σ

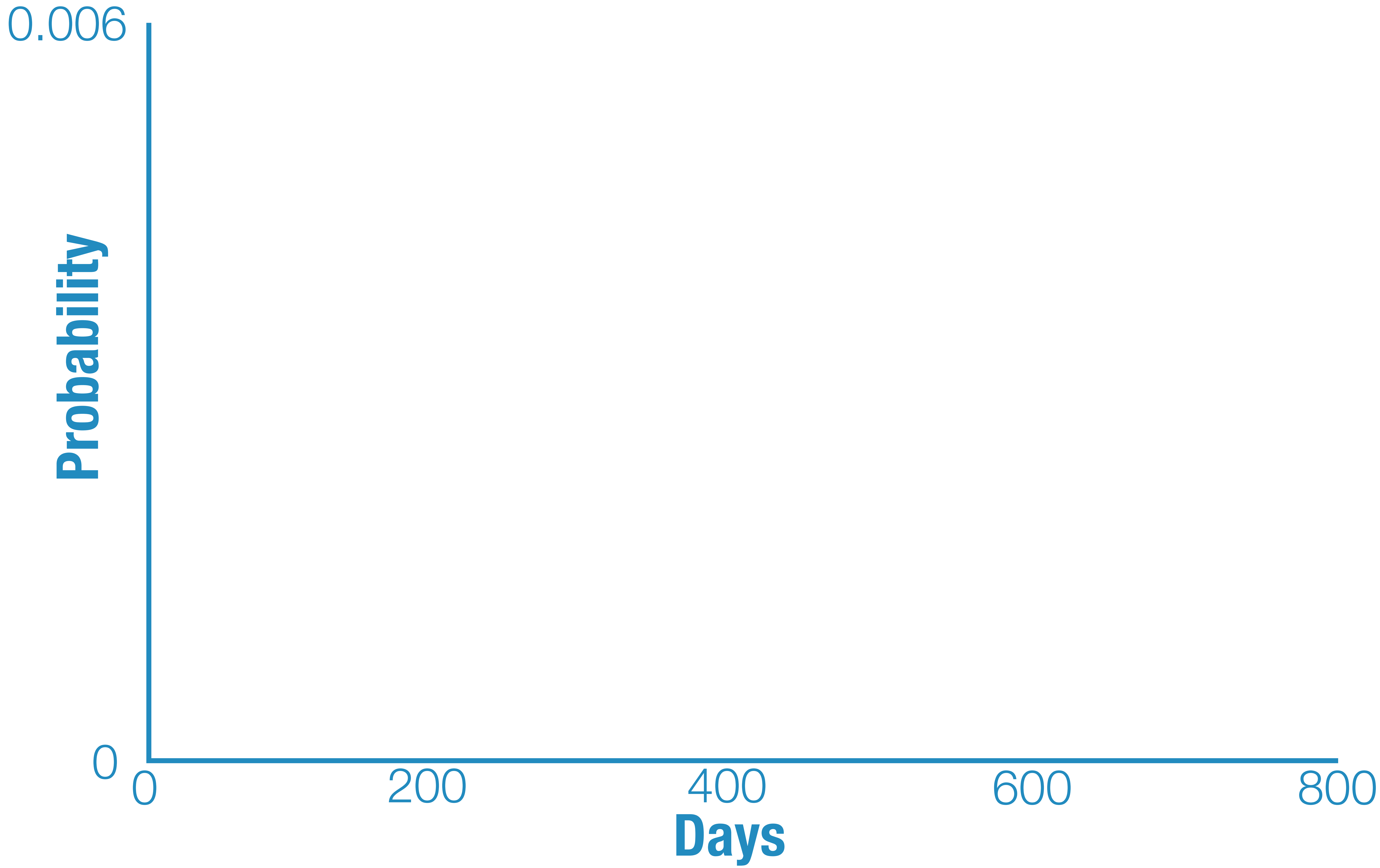


LoC : 1.8 M ± 0.08 M @ 1σ

Author present : 19% ± 4% @ 1σ

How long for seven to produce 100 000 lines of code?

Probability density from 1000 simulations



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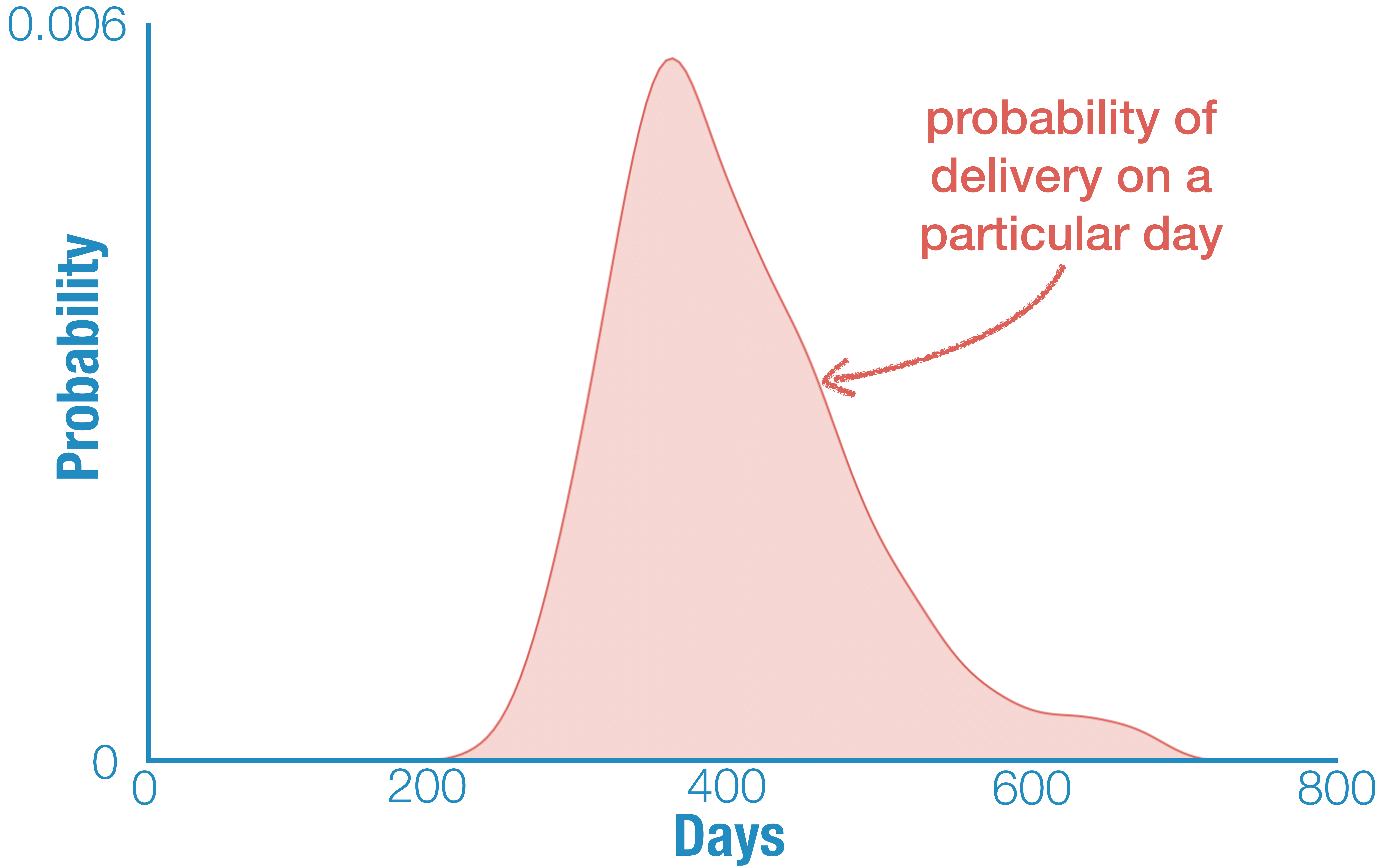

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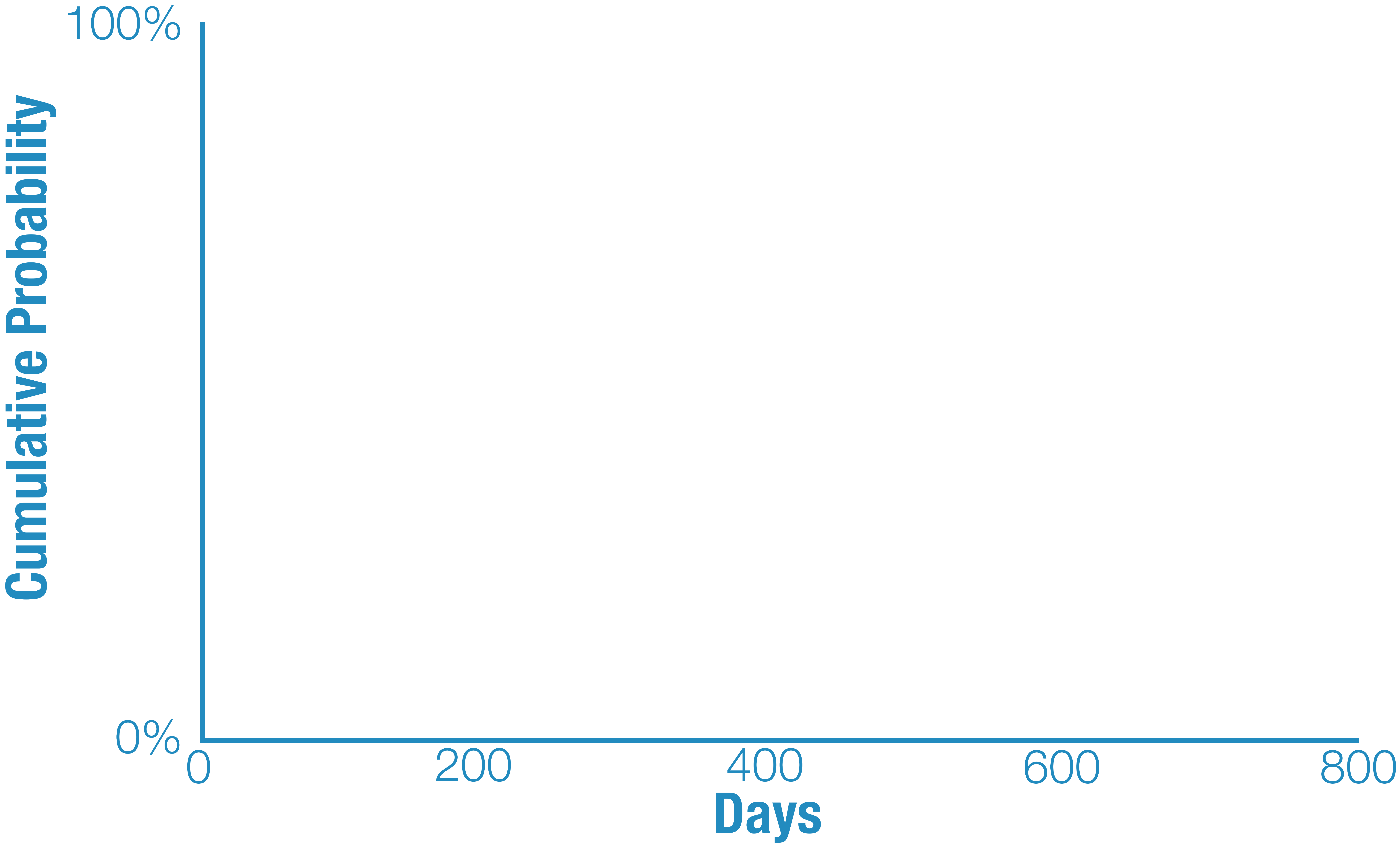

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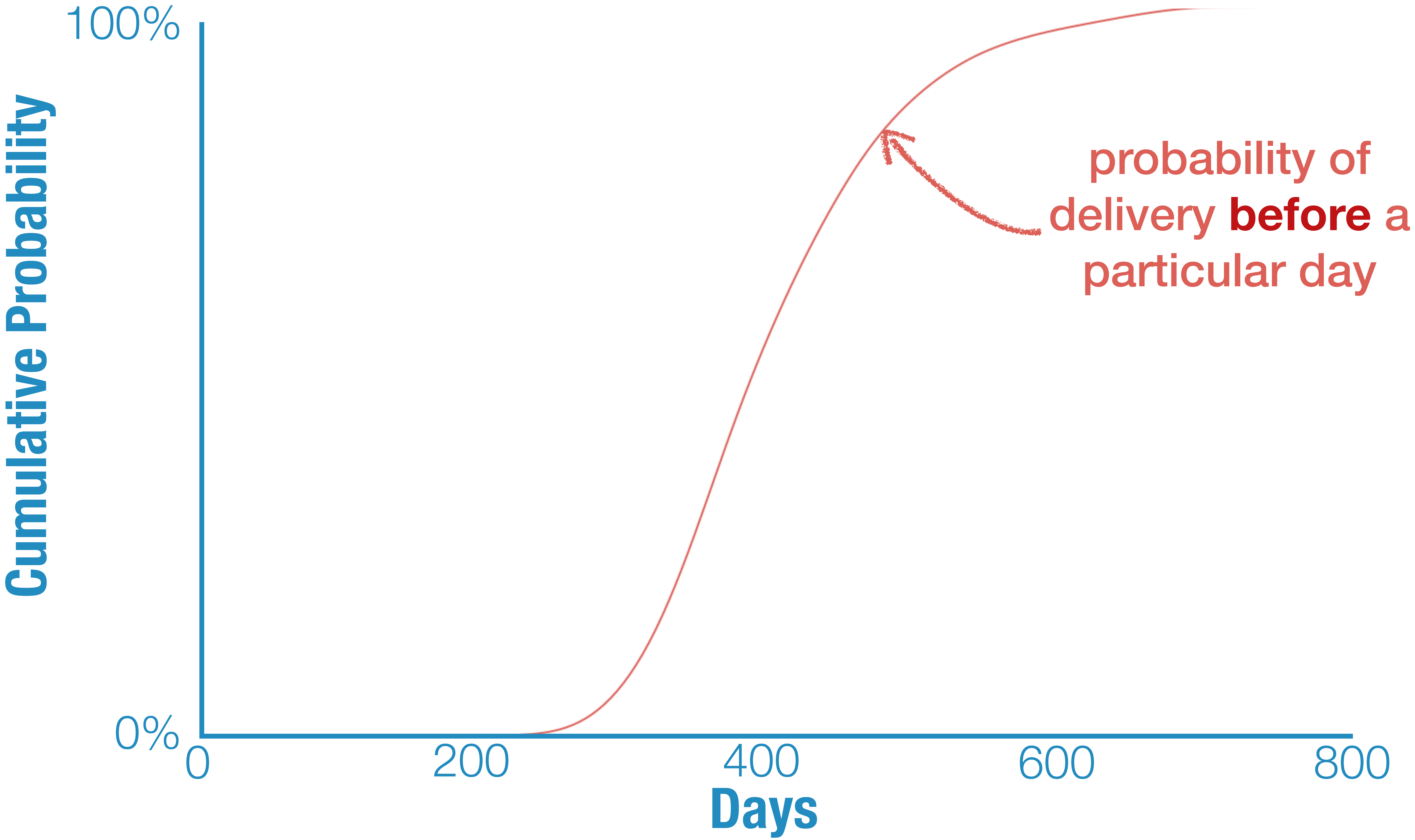

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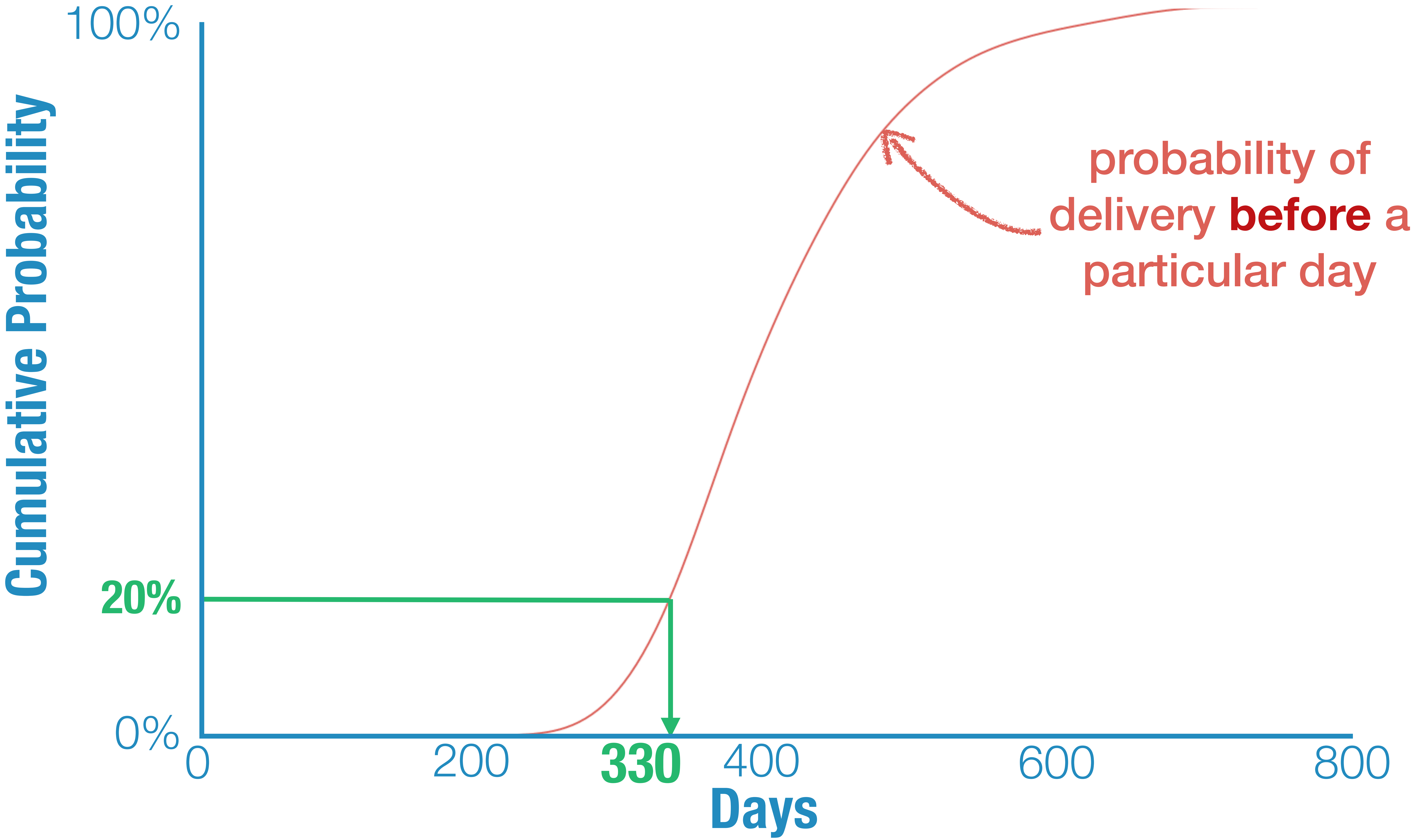

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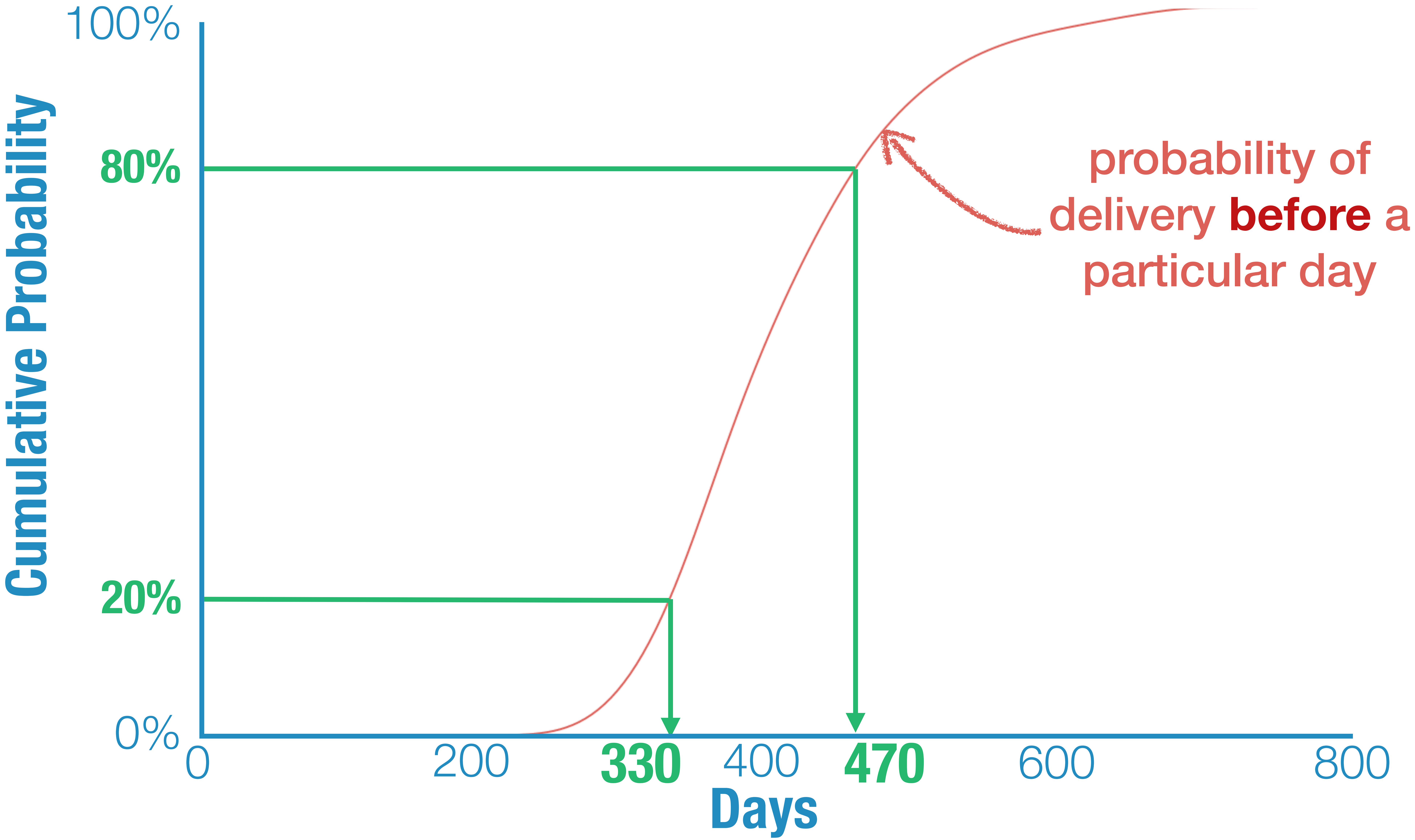
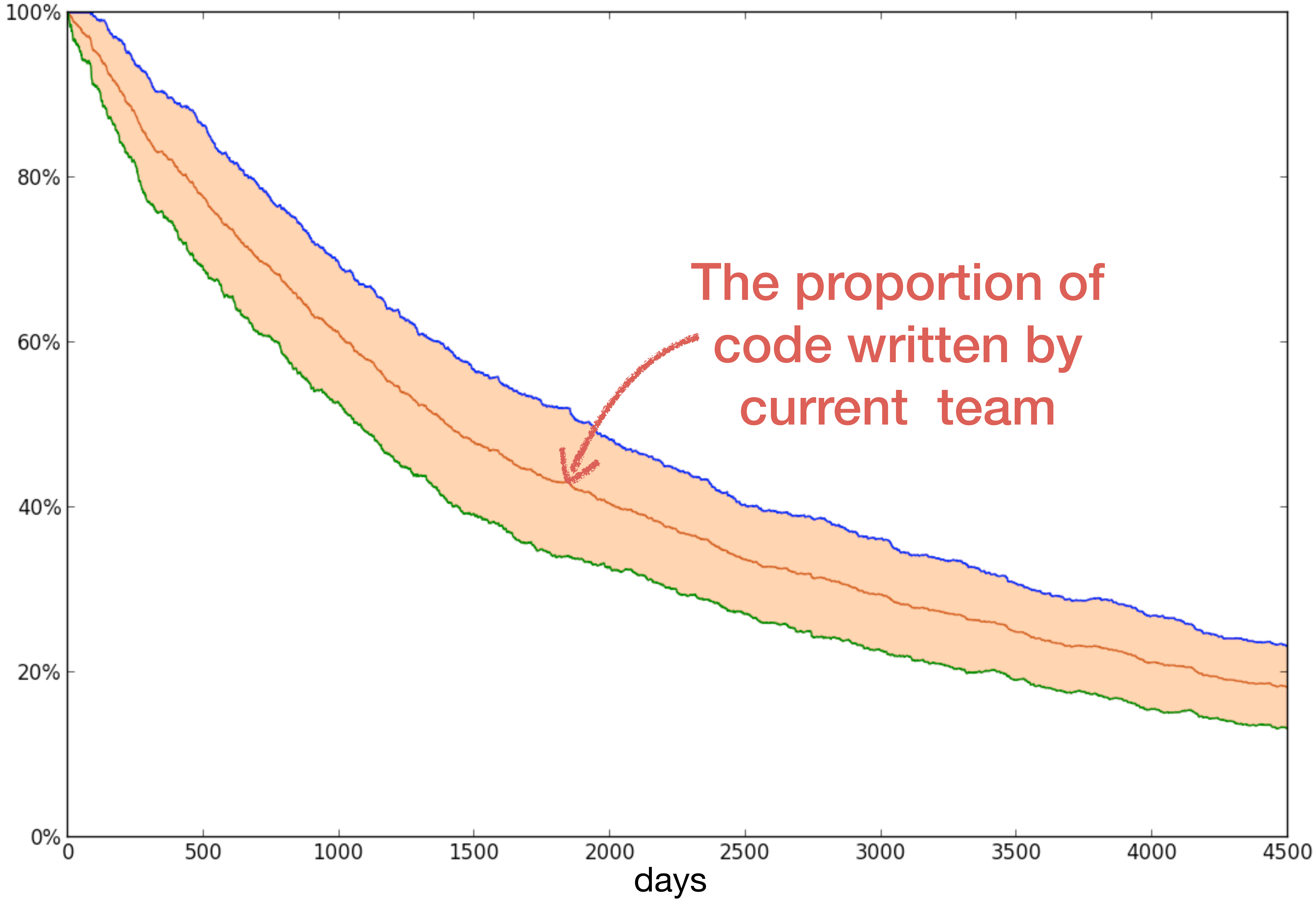


Who can you still talk to?

Most authors of your product quit way back when



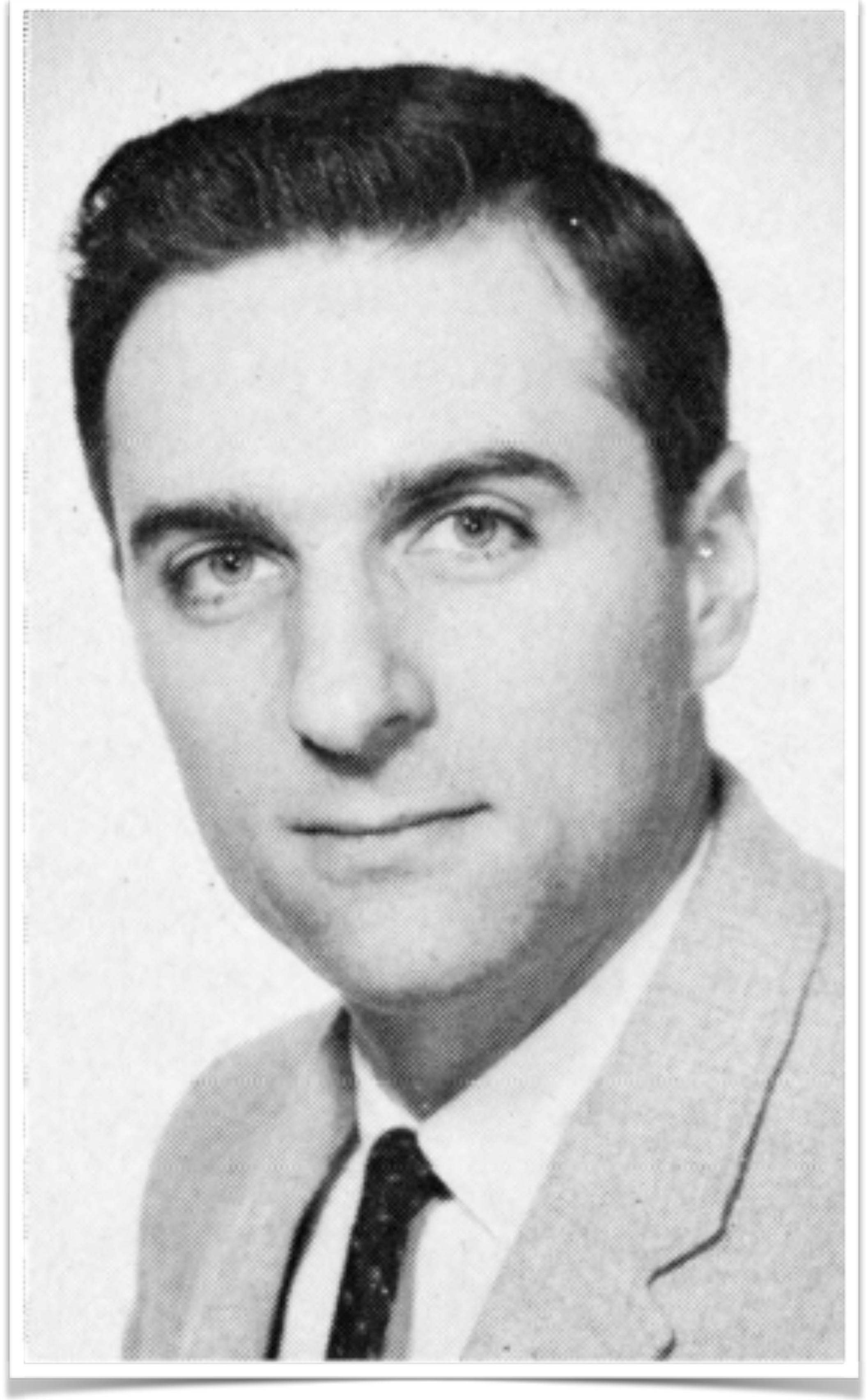
20% after 20 years

Conway's Law

from the 1968 paper *How do committees invent?*

"Any organization that designs a system (defined broadly) will produce a design whose structure is a copy of the organization's communication structure"

integrated over time



Melvin Conway

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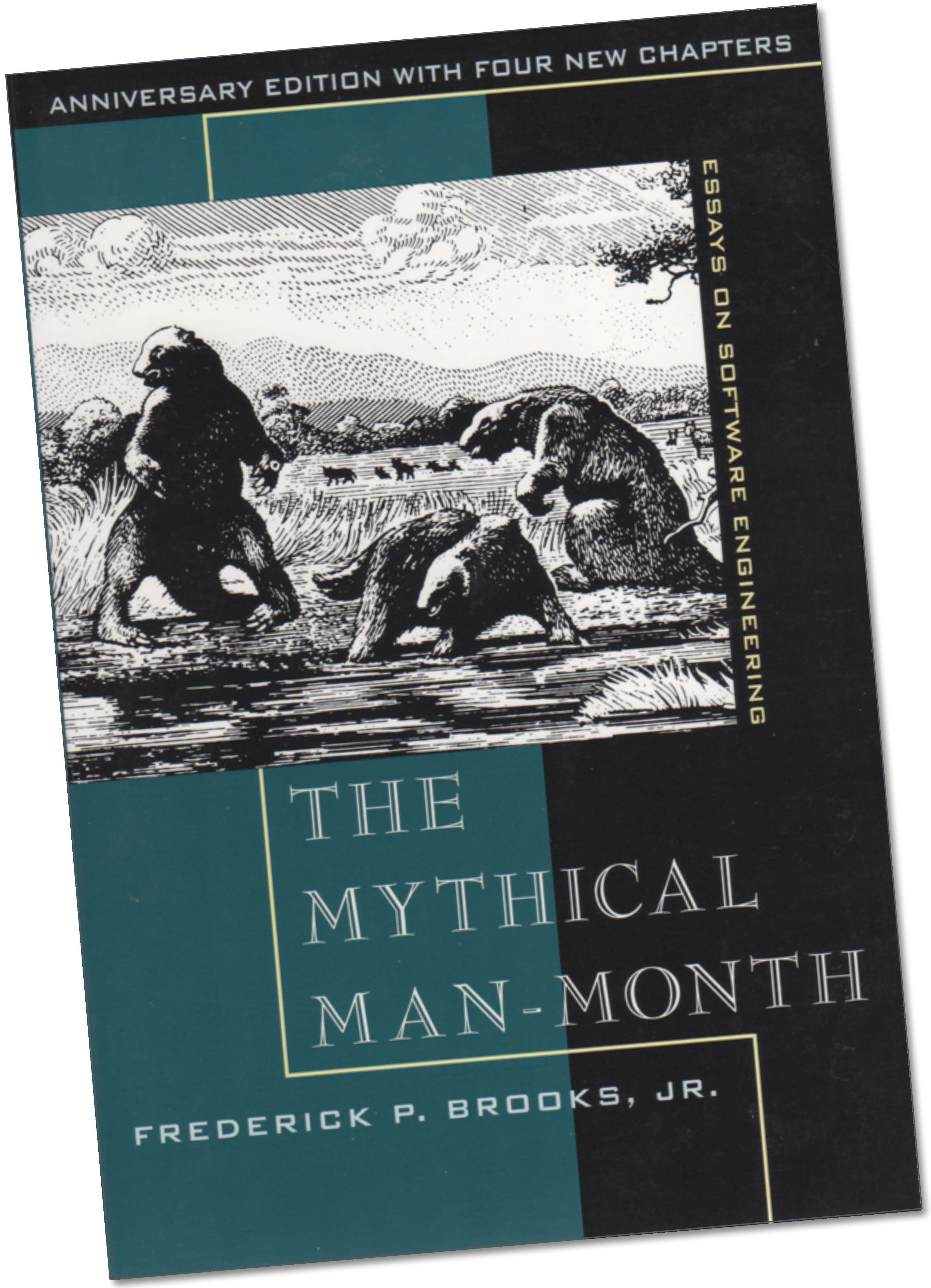
ANNIVERSARY EDITION WITH FOUR NEW CHAPTERS
ESSAYS ON SOFTWARE ENGINEERING
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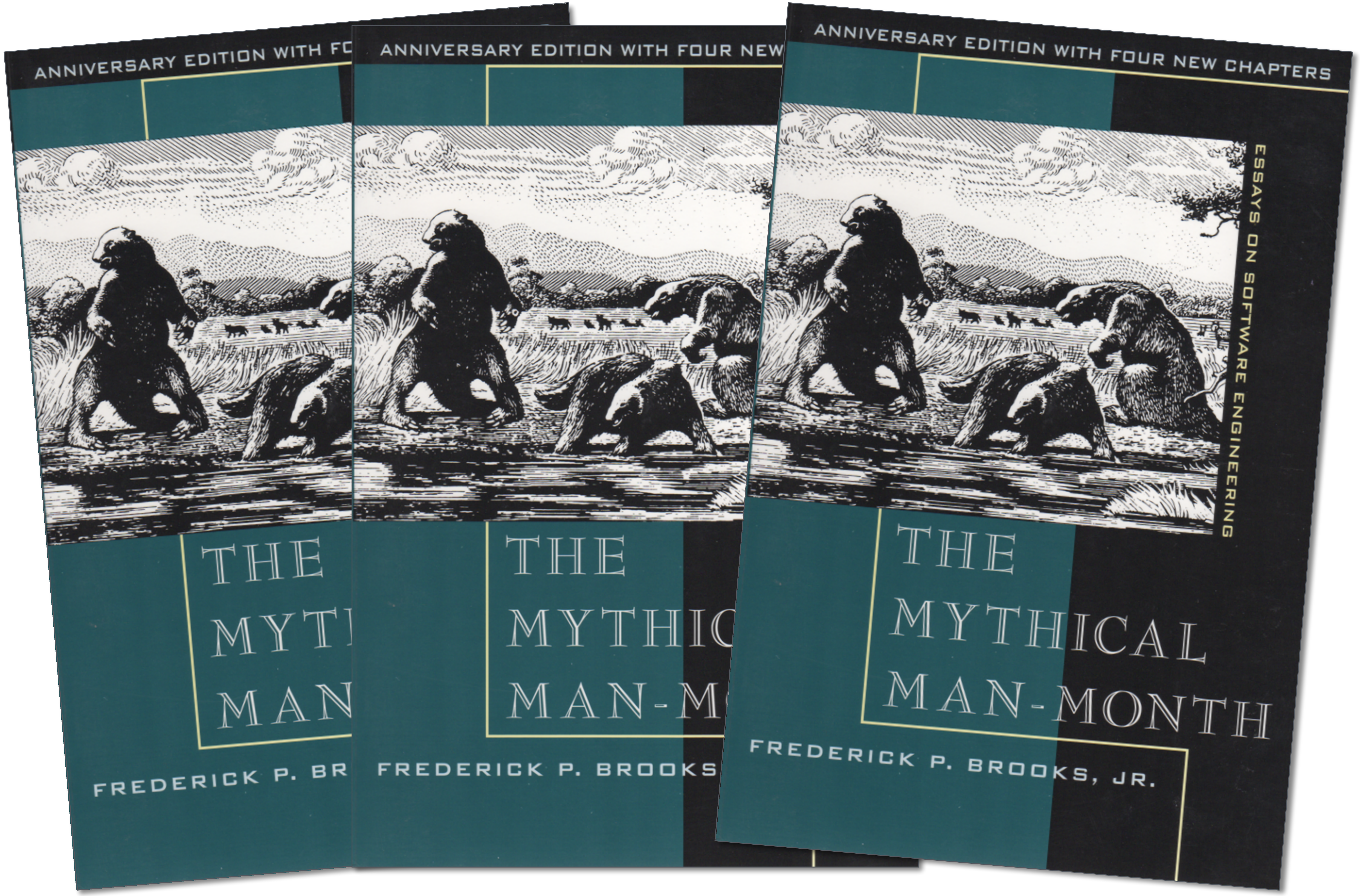
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Charles R Knight (1921) *Rancho la Brea Tar Pool*

“Adding manpower to a late software project makes it later.”

Fred Brooks / The Mythical Man-Month

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Formulate a hypothesis.

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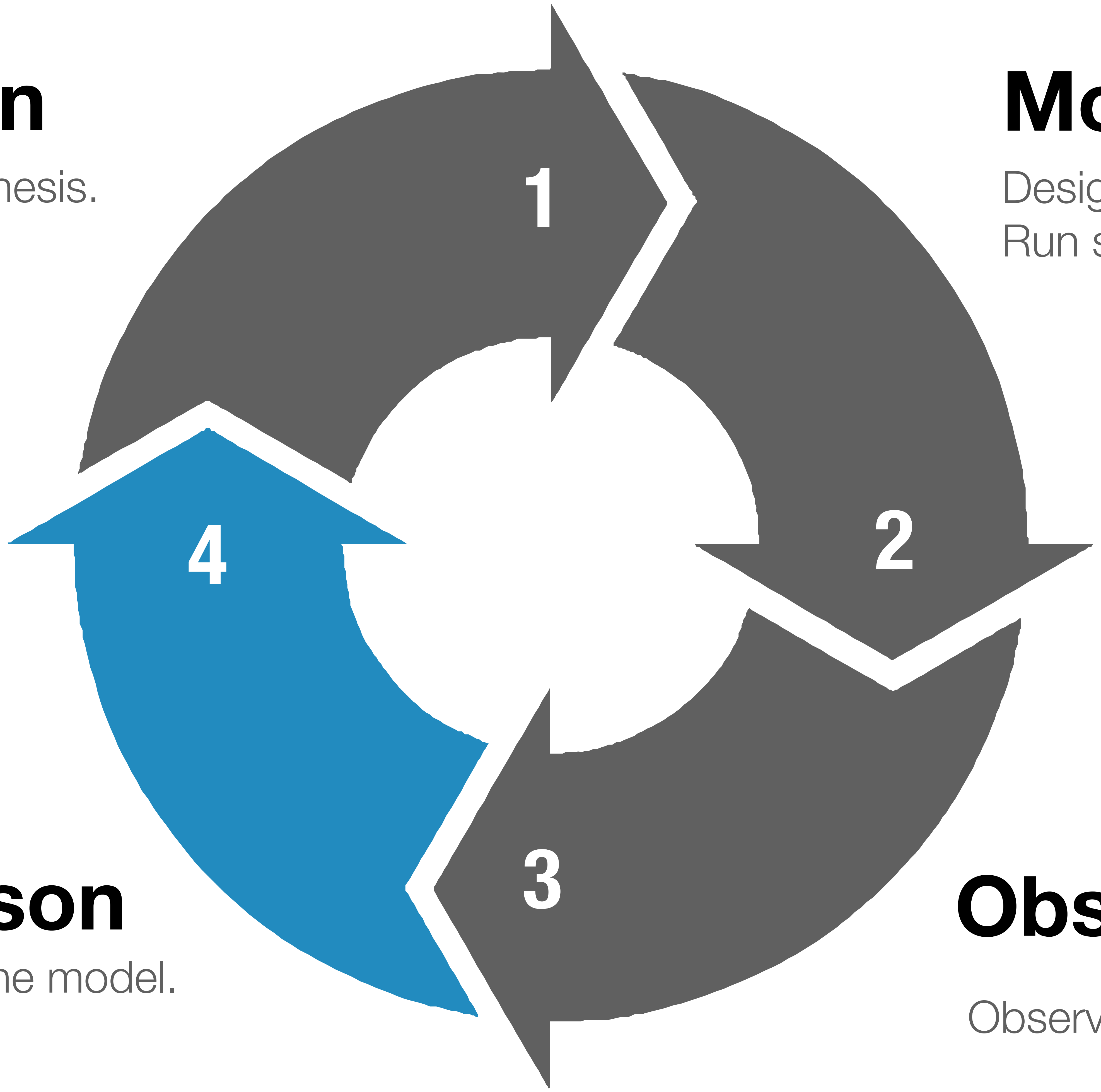
Run simulations.



Comparison

Validate or refute the model.

Observation

Observe and record reality.

System dynamics simulations

Model systems for improving structures, policies and interventions

- Define problem dynamically – over time
- Endogenous view of significant dynamics
- Model reproduces problem of concern
- Derive understanding

Discrete versus continuous modelling

Events or equations?

Discrete versus continuous modelling

Events or equations?

Discrete

- Individuals
- Populations
- Definite events
- Probability distributions
- Stochastic
- Concrete scenarios
- Harder to formulate as code

Discrete versus continuous modelling

Events or equations?

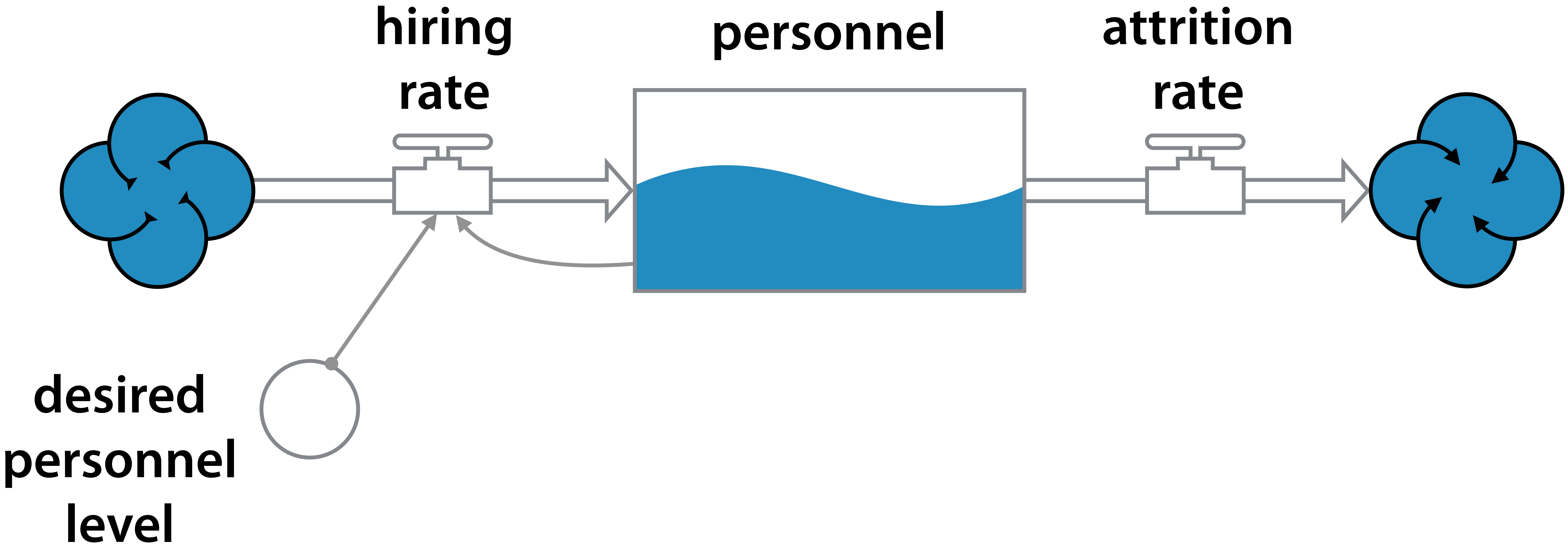
Discrete

- Individuals
- Populations
- Definite events
- Probability distributions
- Stochastic
- Concrete scenarios
- Harder to formulate as code

Continuous

- Aggregates
- Levels of quantities
- Flow rates
- Equations
- Numerical / analytical solutions
- More abstract
- Easier to formulate as code

Elements of continuous models



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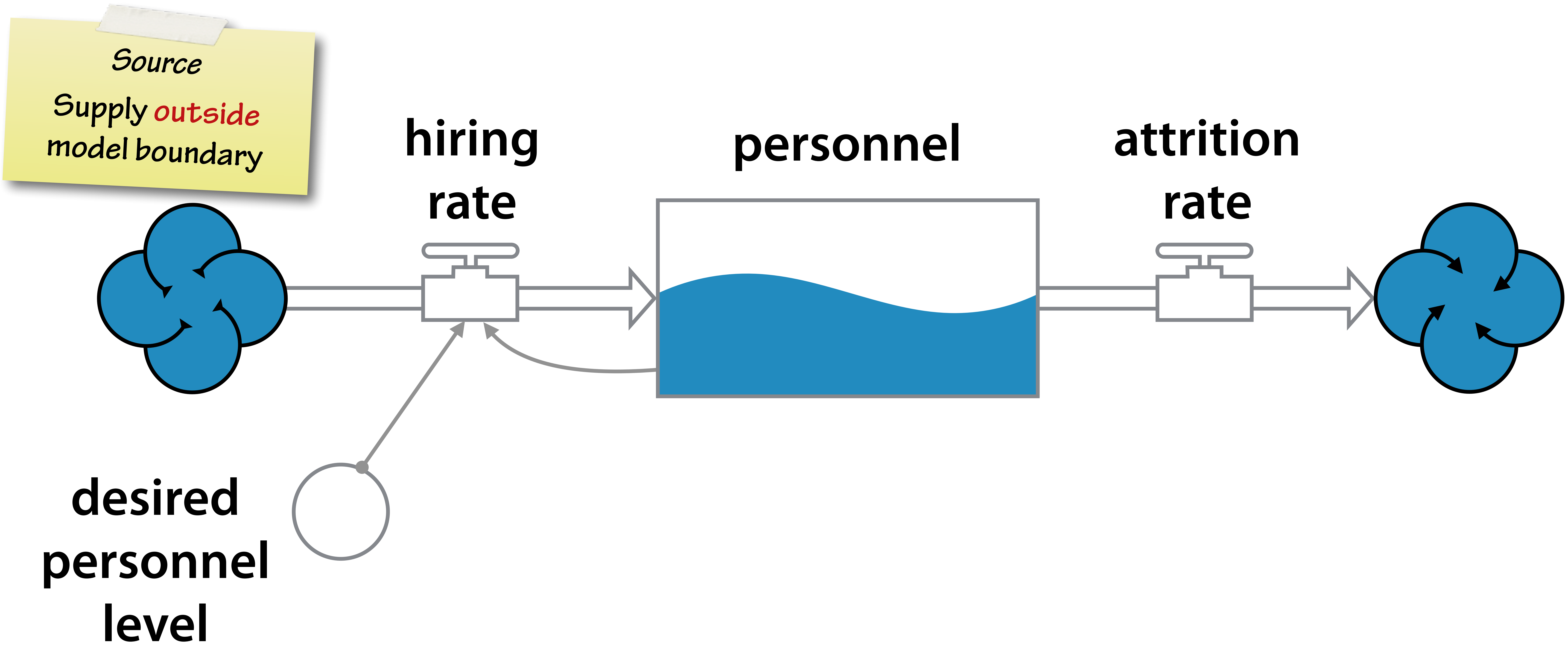

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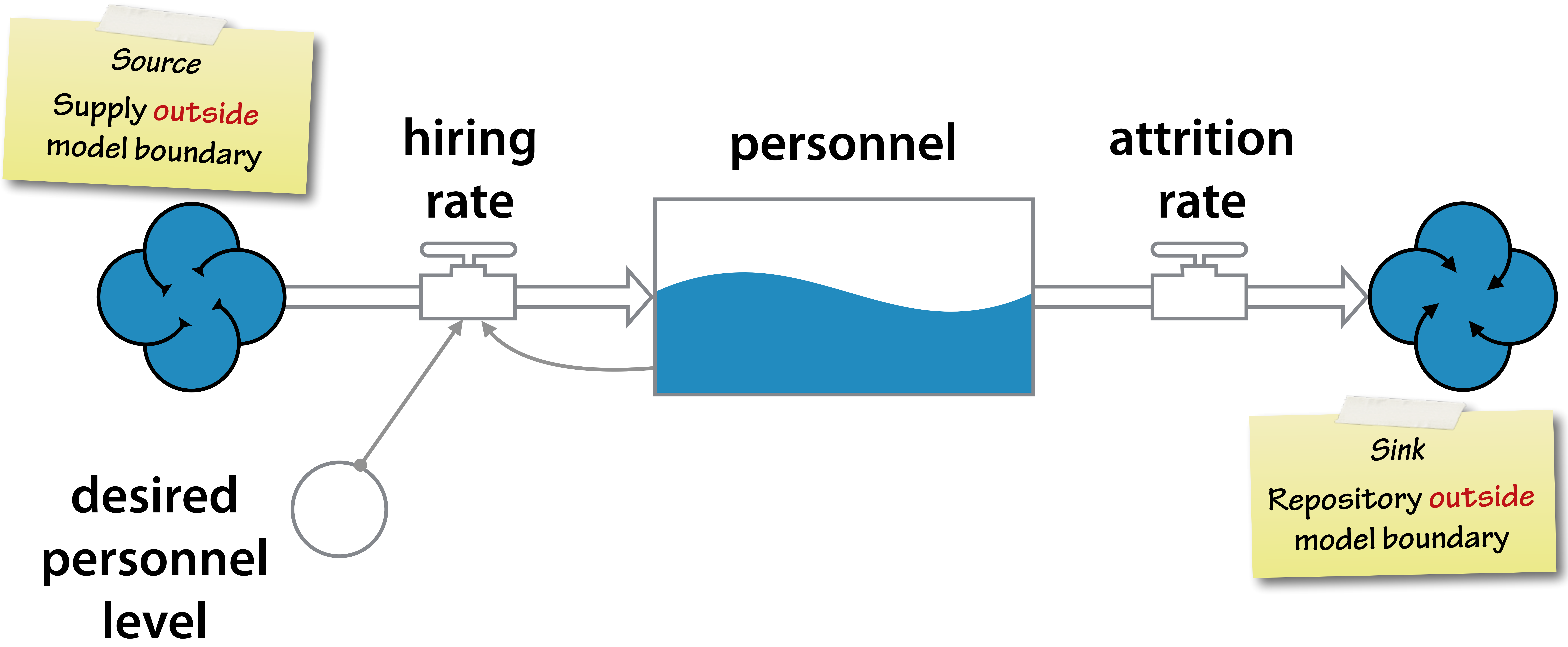

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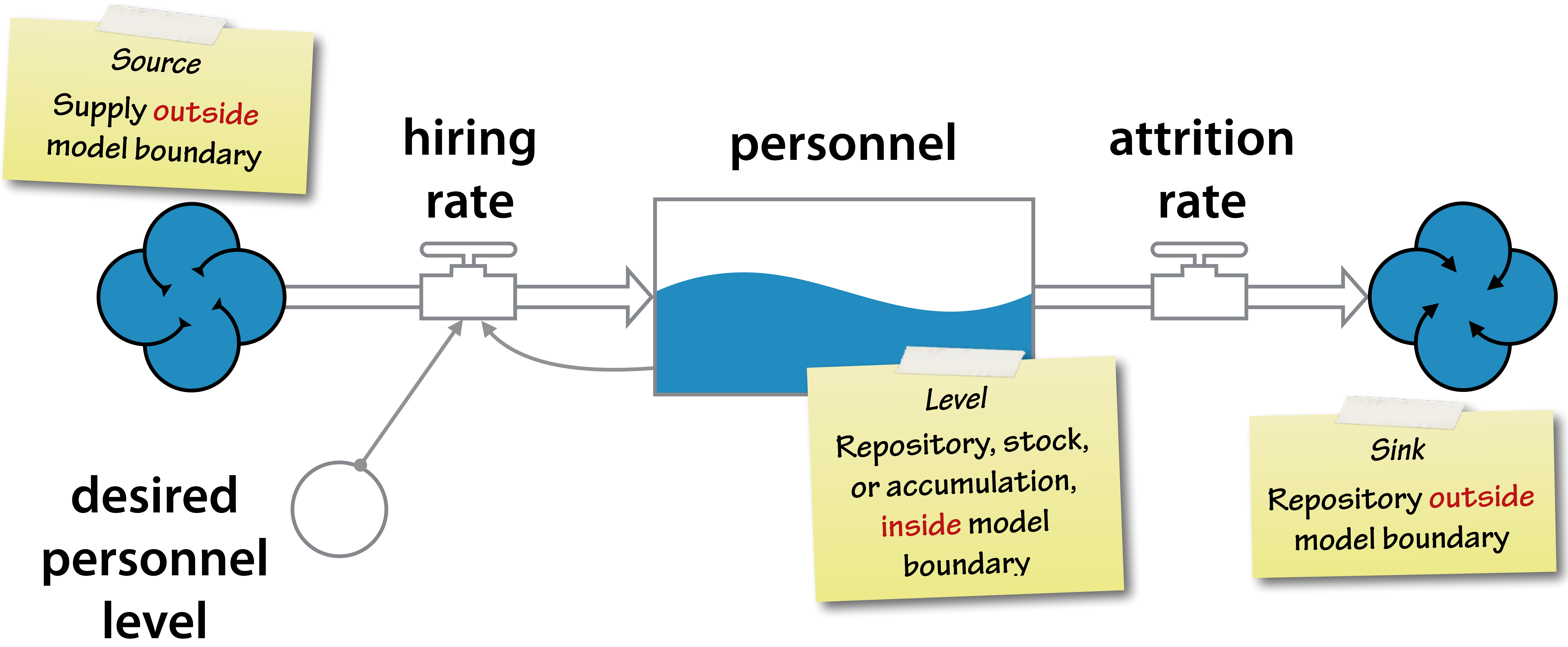

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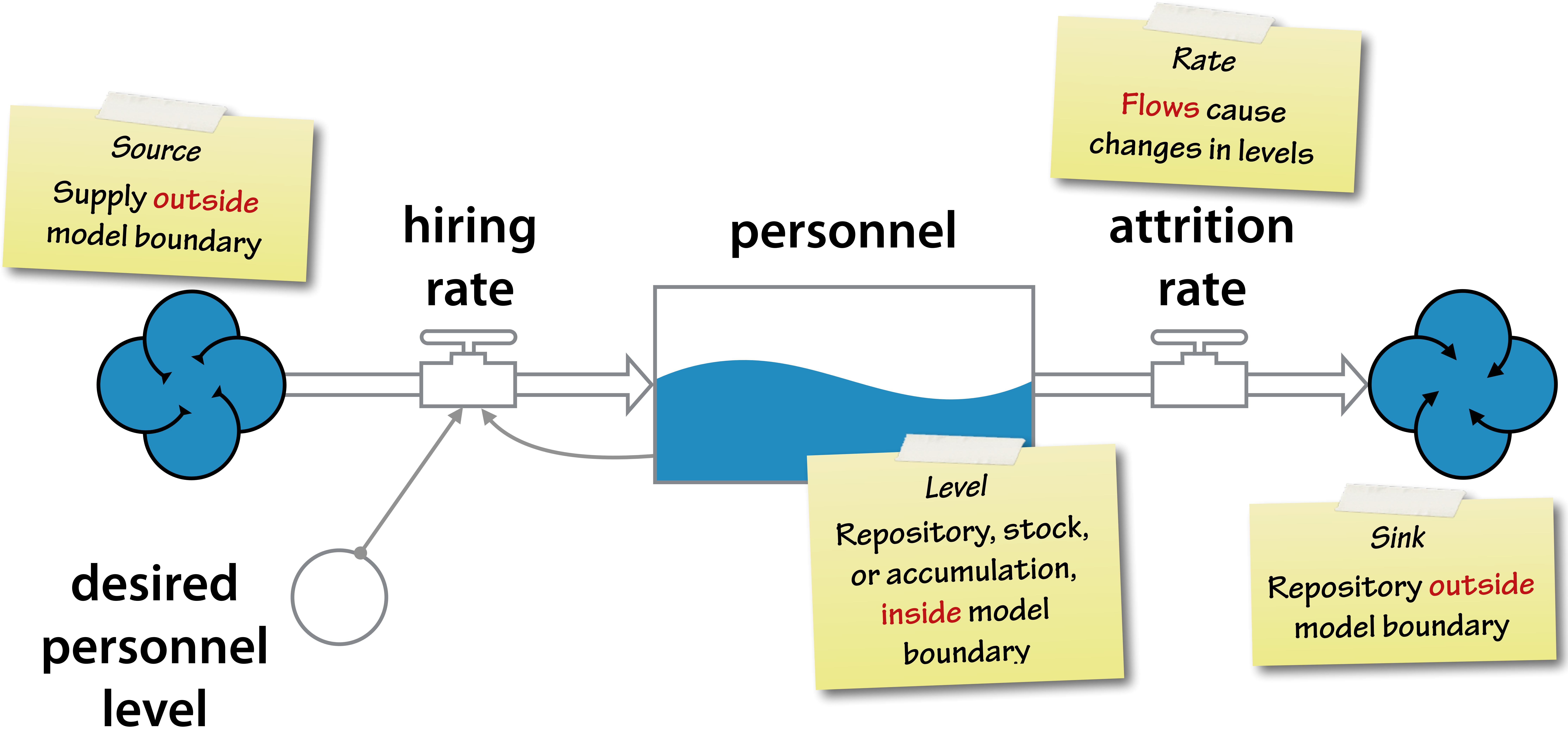

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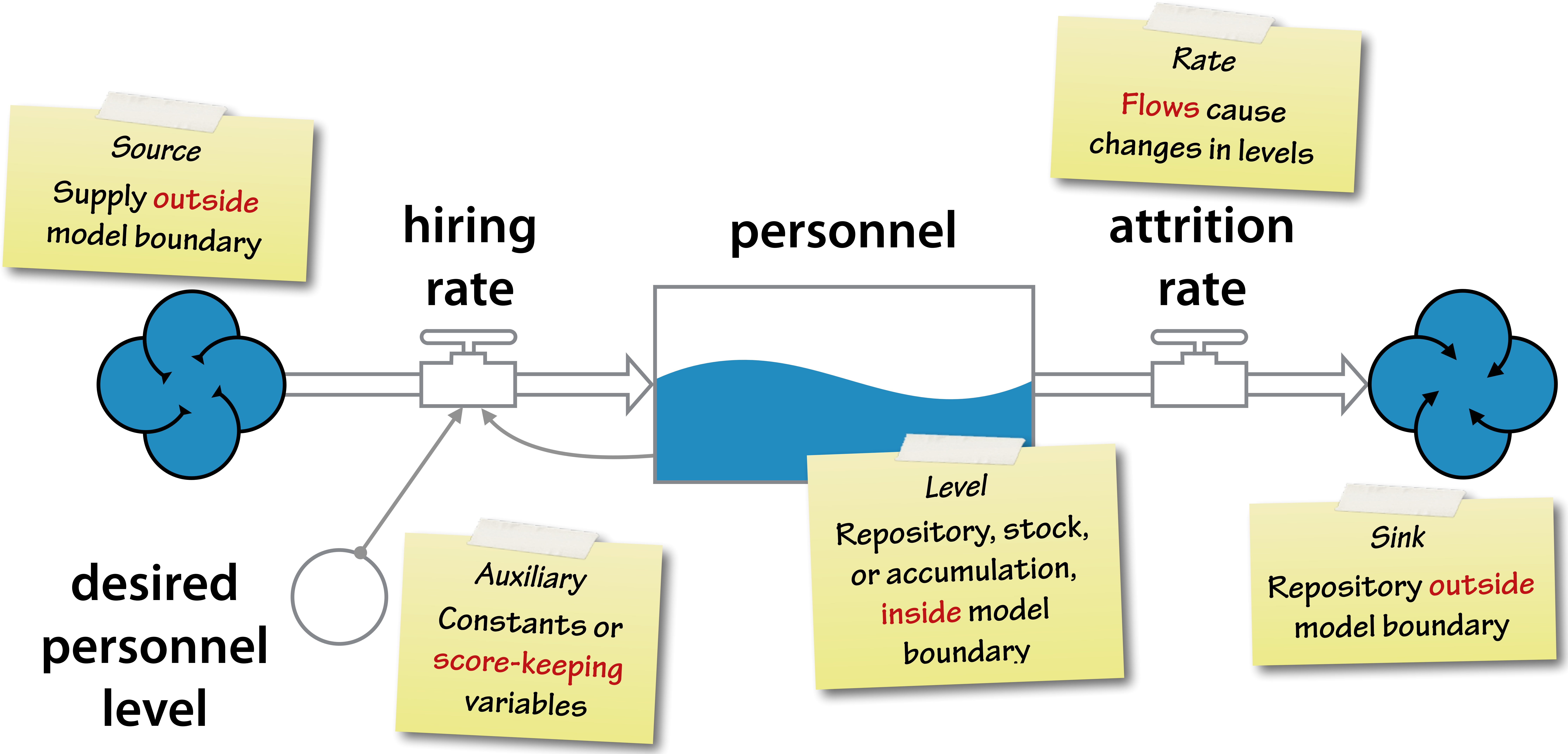
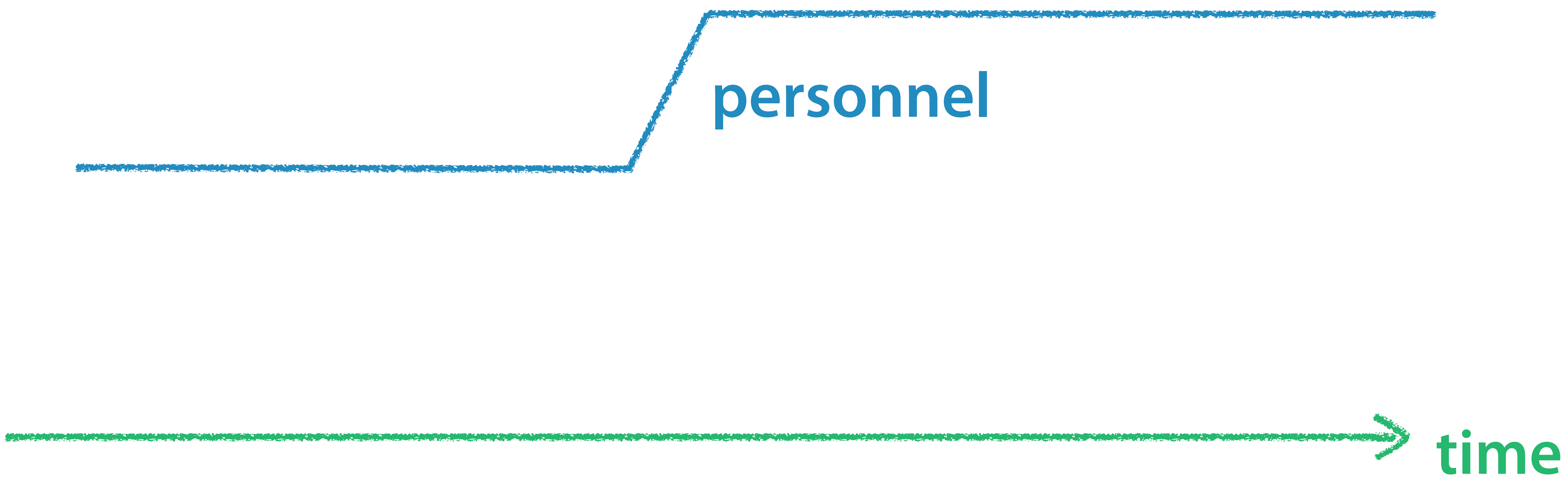


Brooks' Law

Reference behaviour

Brooks' Law

Reference behaviour



Brooks' Law

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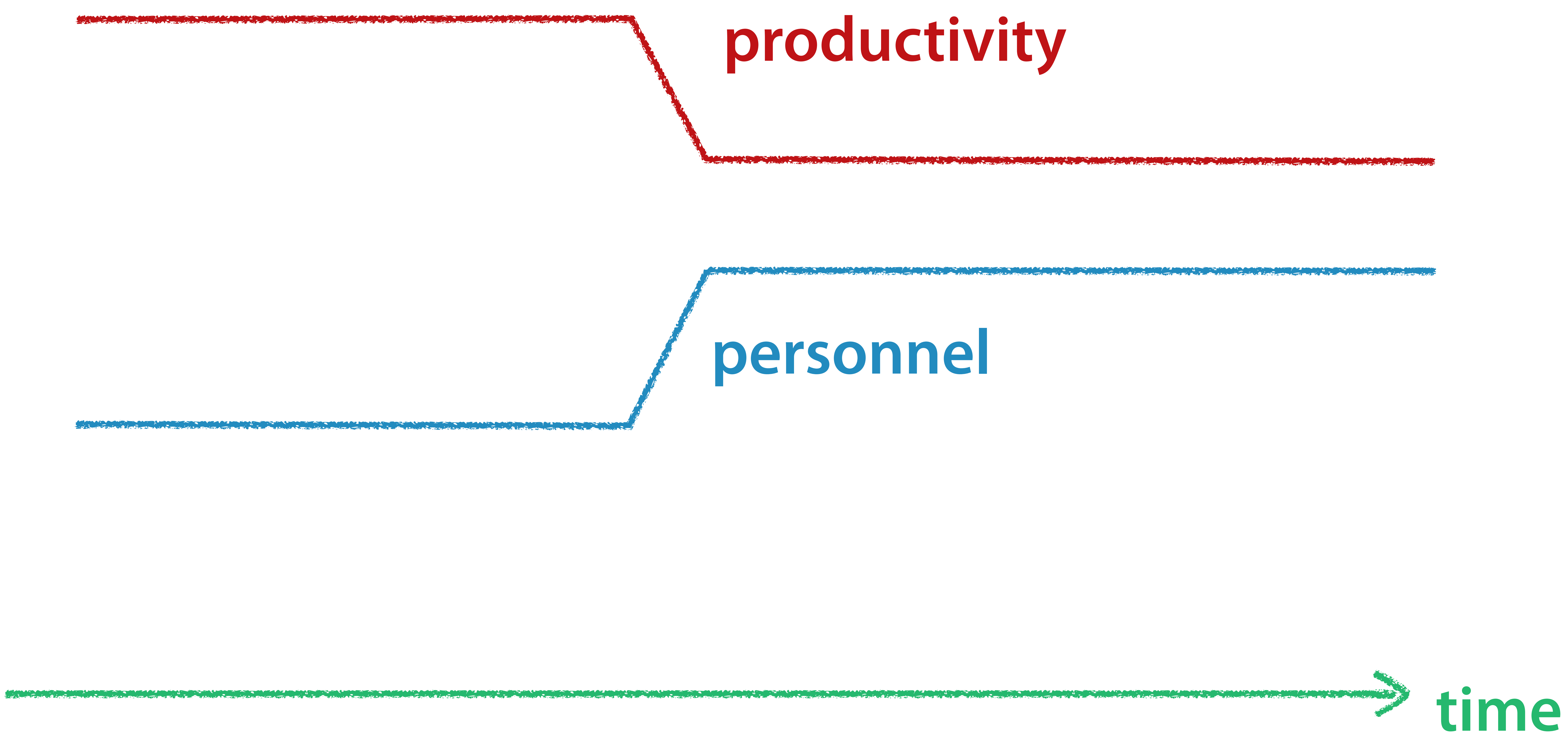
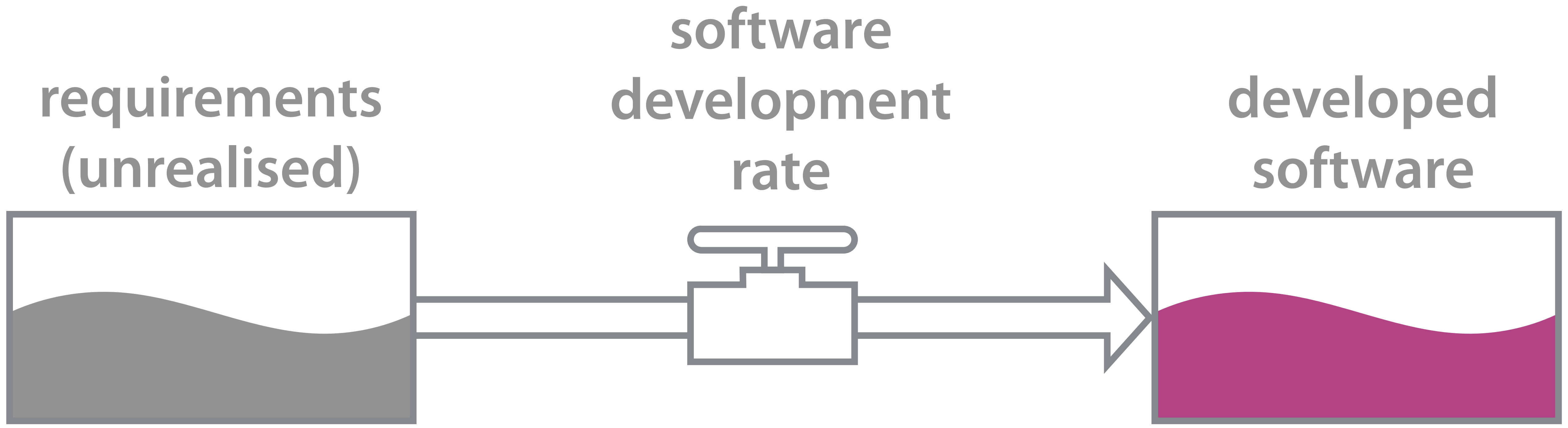


Brooks' Law model



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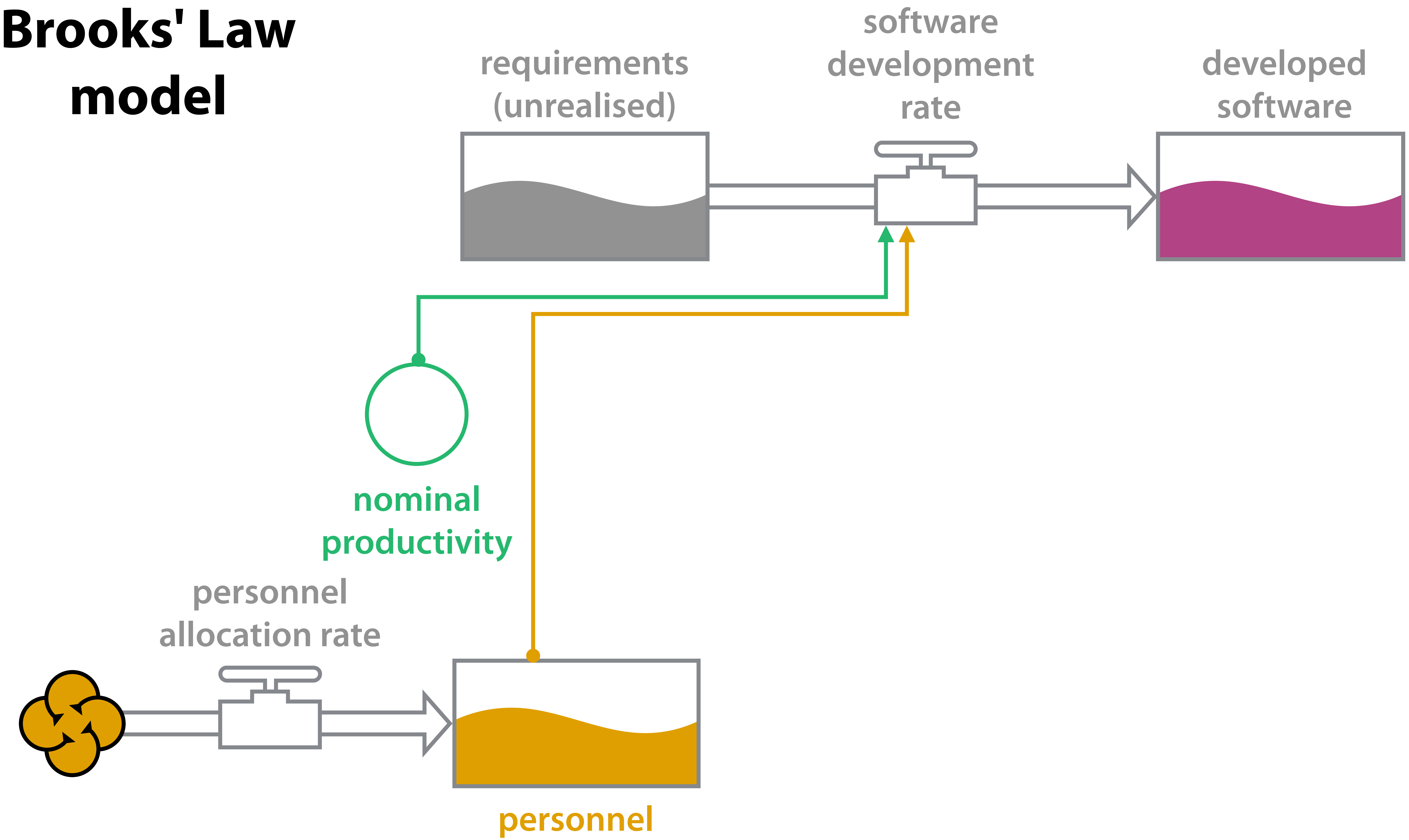
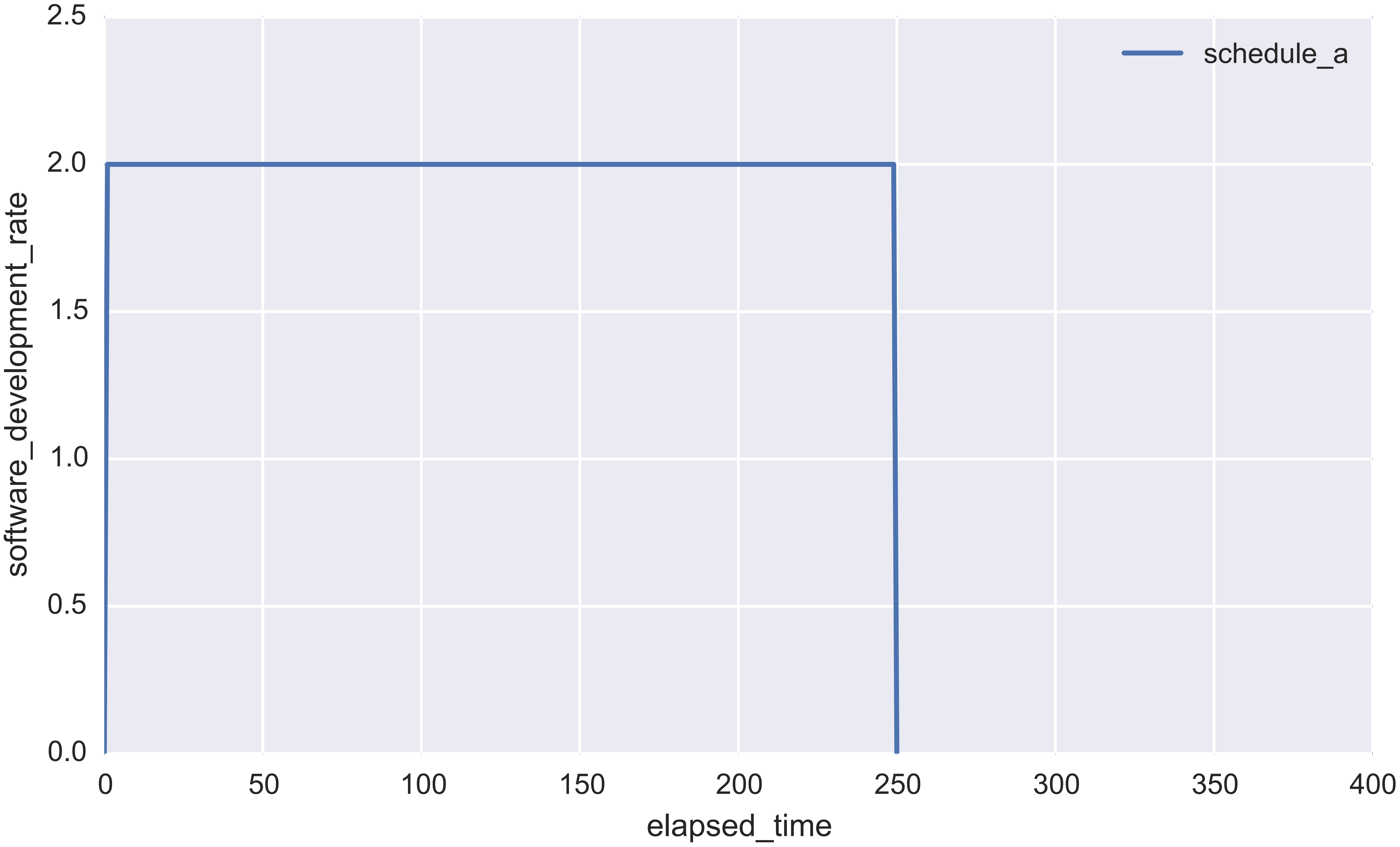
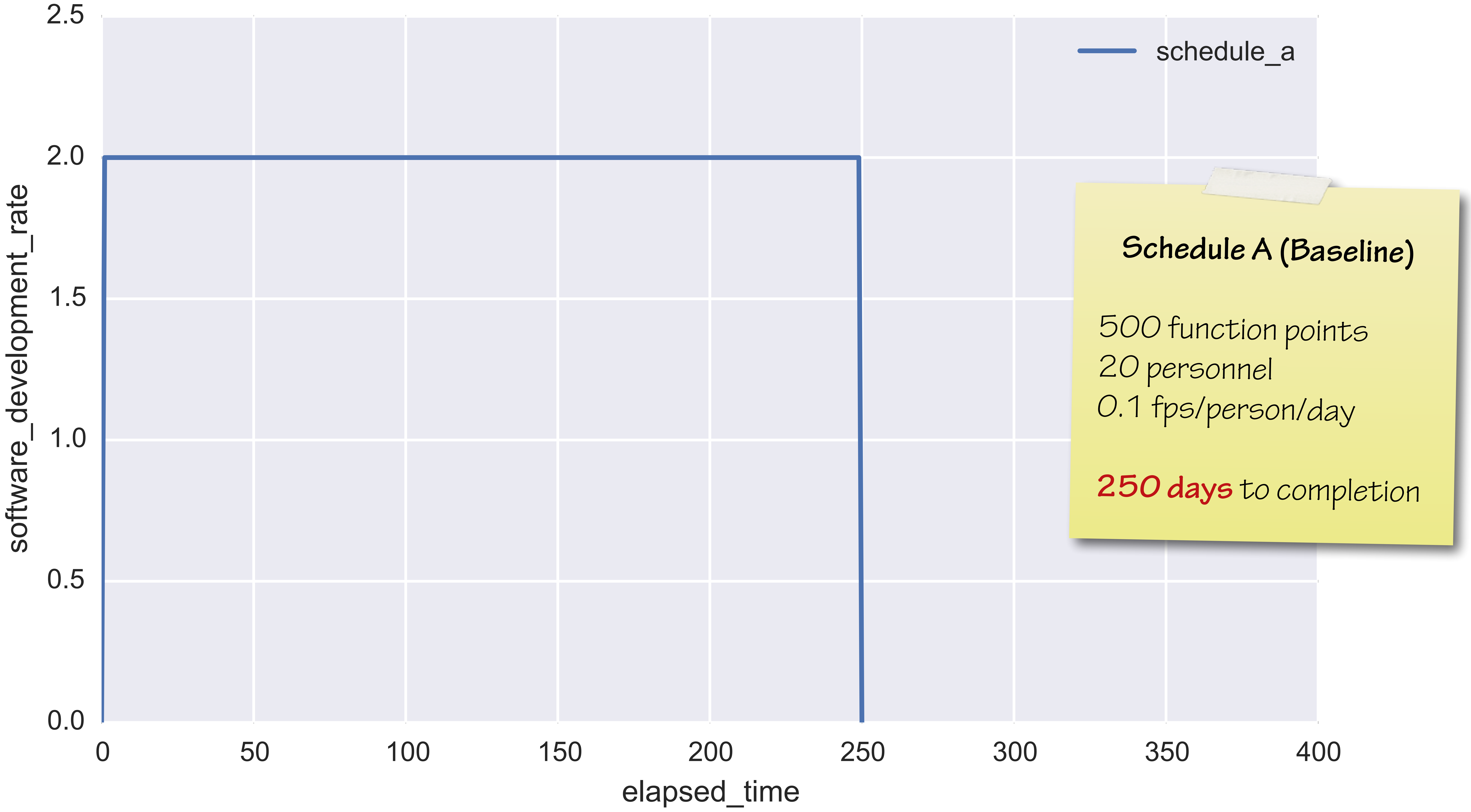




schedule_a
software_development_rate
elapsed_time
0.0
0.5
1.0
1.5
2.0
2.5
0
50
100
150
200
250
300
350
400



2.5
2.0
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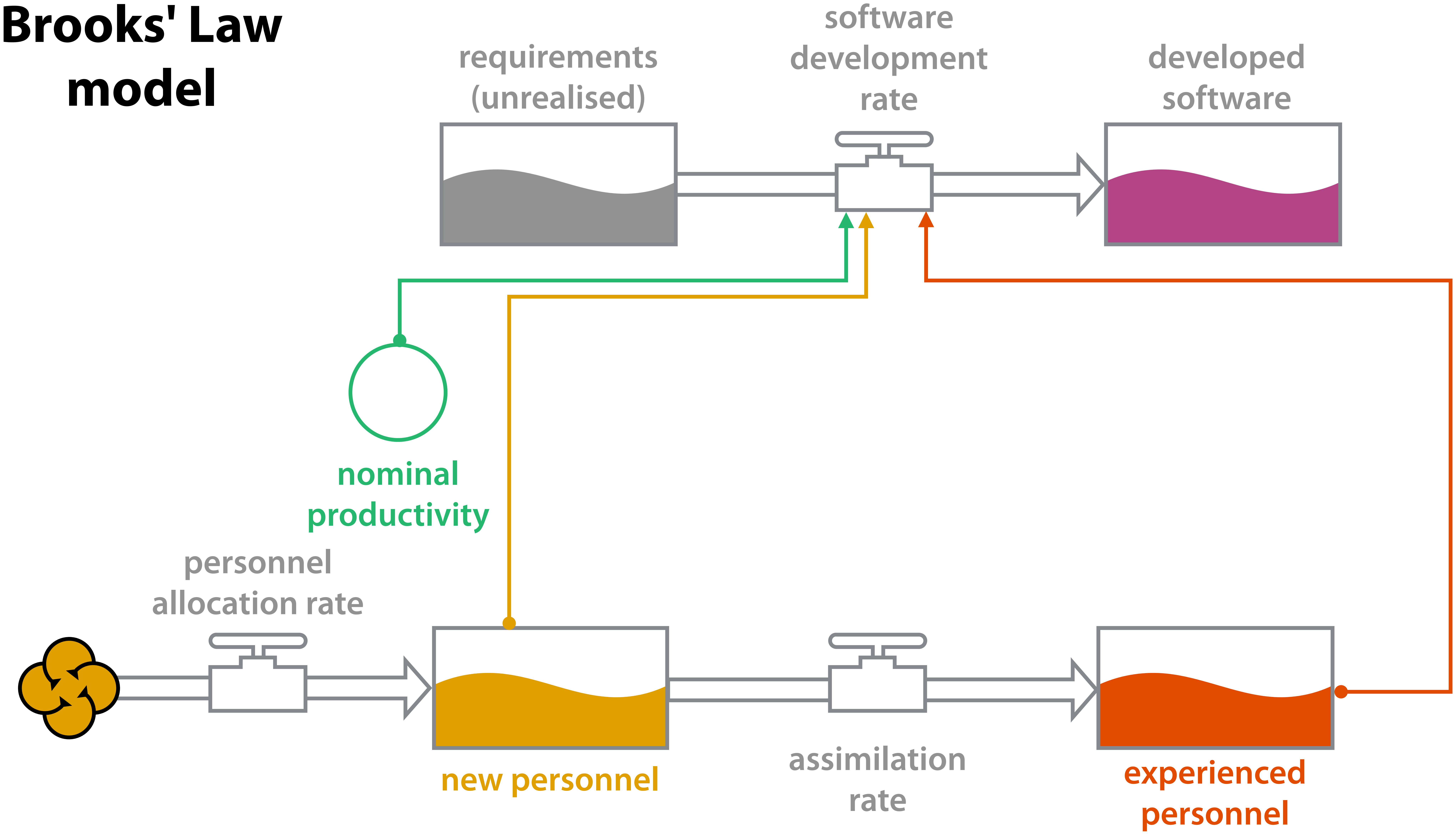
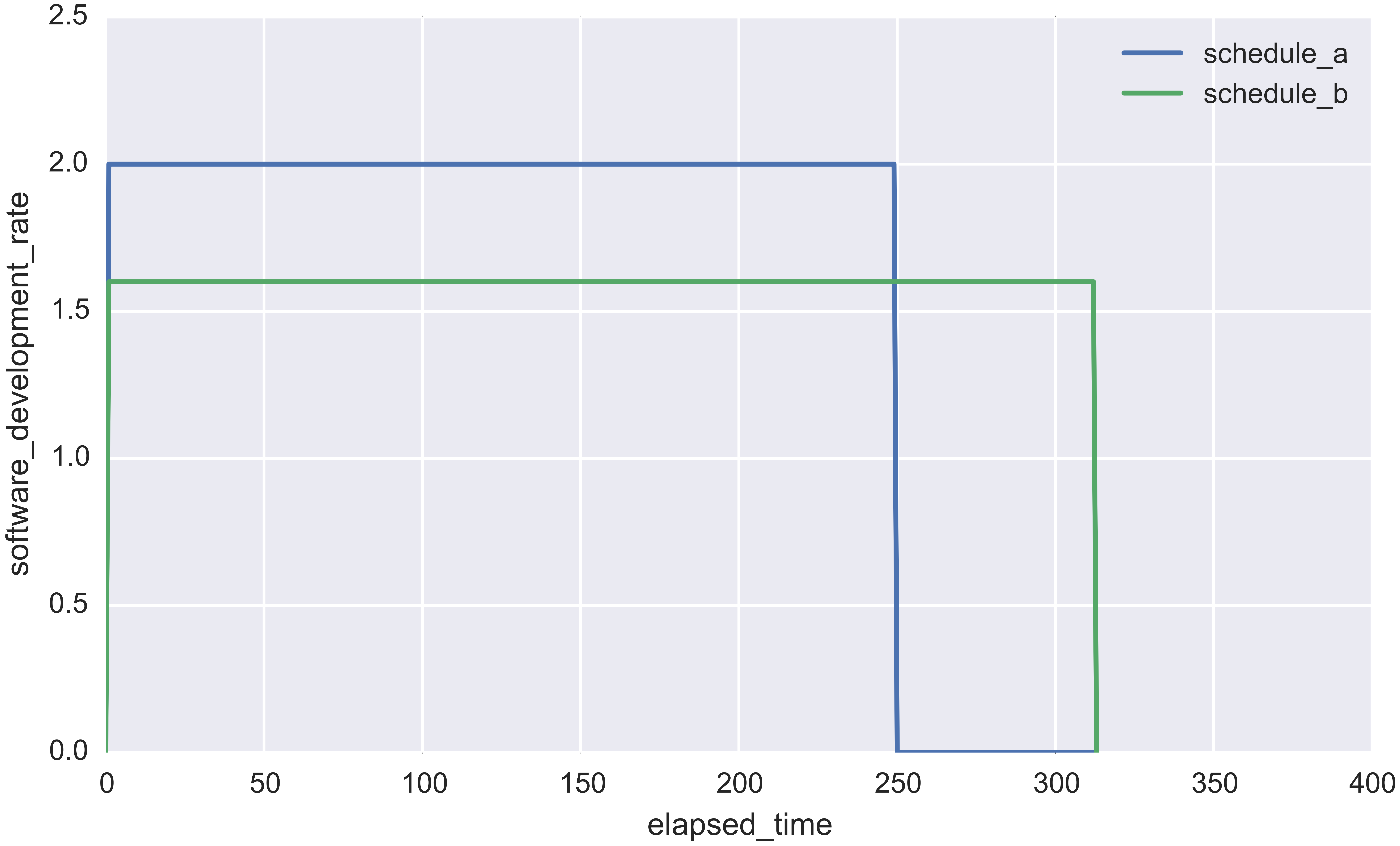
0.0
software_development_rate
0
50
100
150
200
250
300
350
400
elapsed_time
schedule_a
Schedule A (Baseline)
500 function points
20 personnel
0.1 fps/person/day
250 days to completion

Brooks' Law model




schedule_a
schedule_b
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software_development_rate
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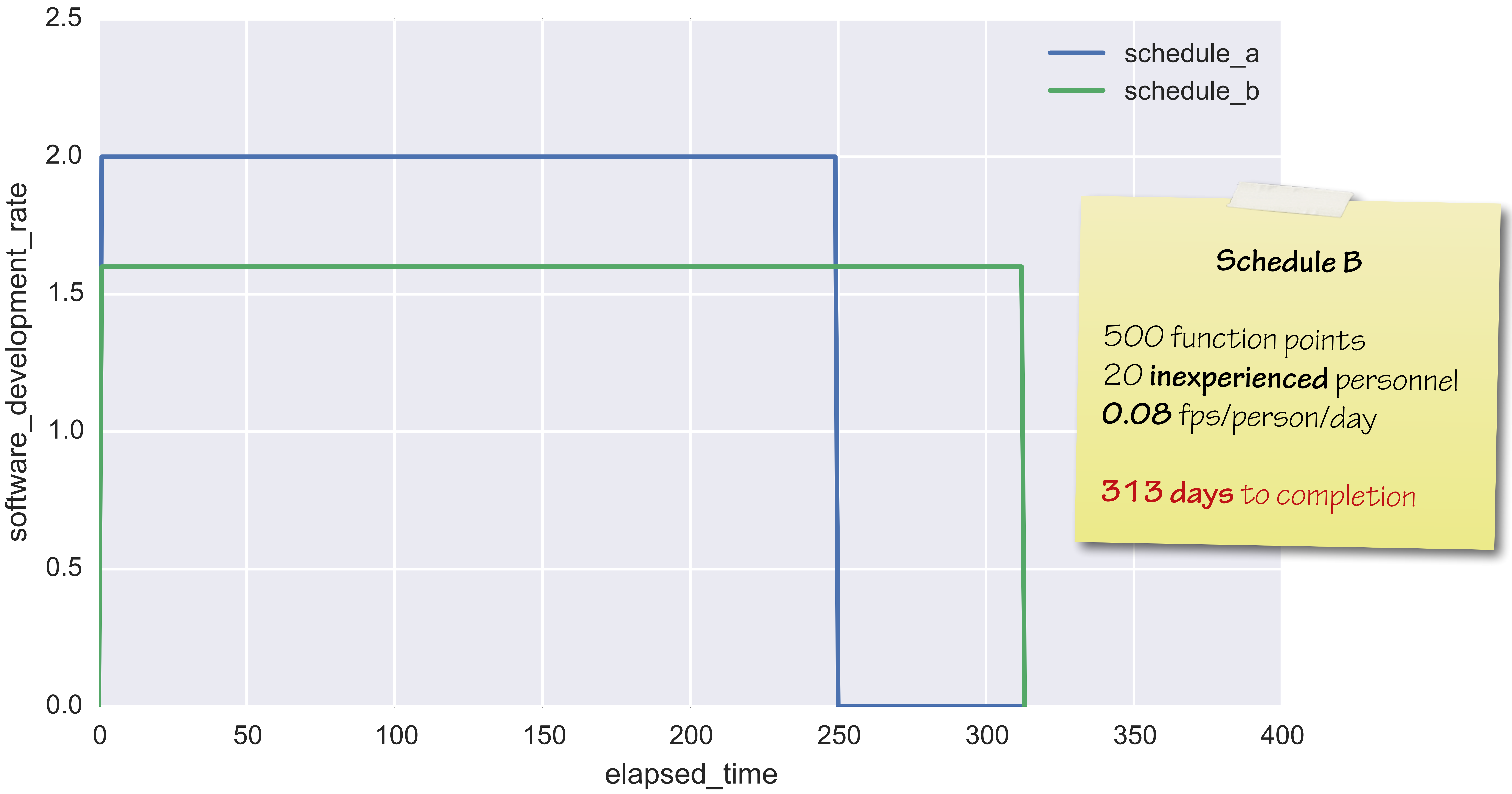
350
400
elapsed_time



2.5
2.0
1.5
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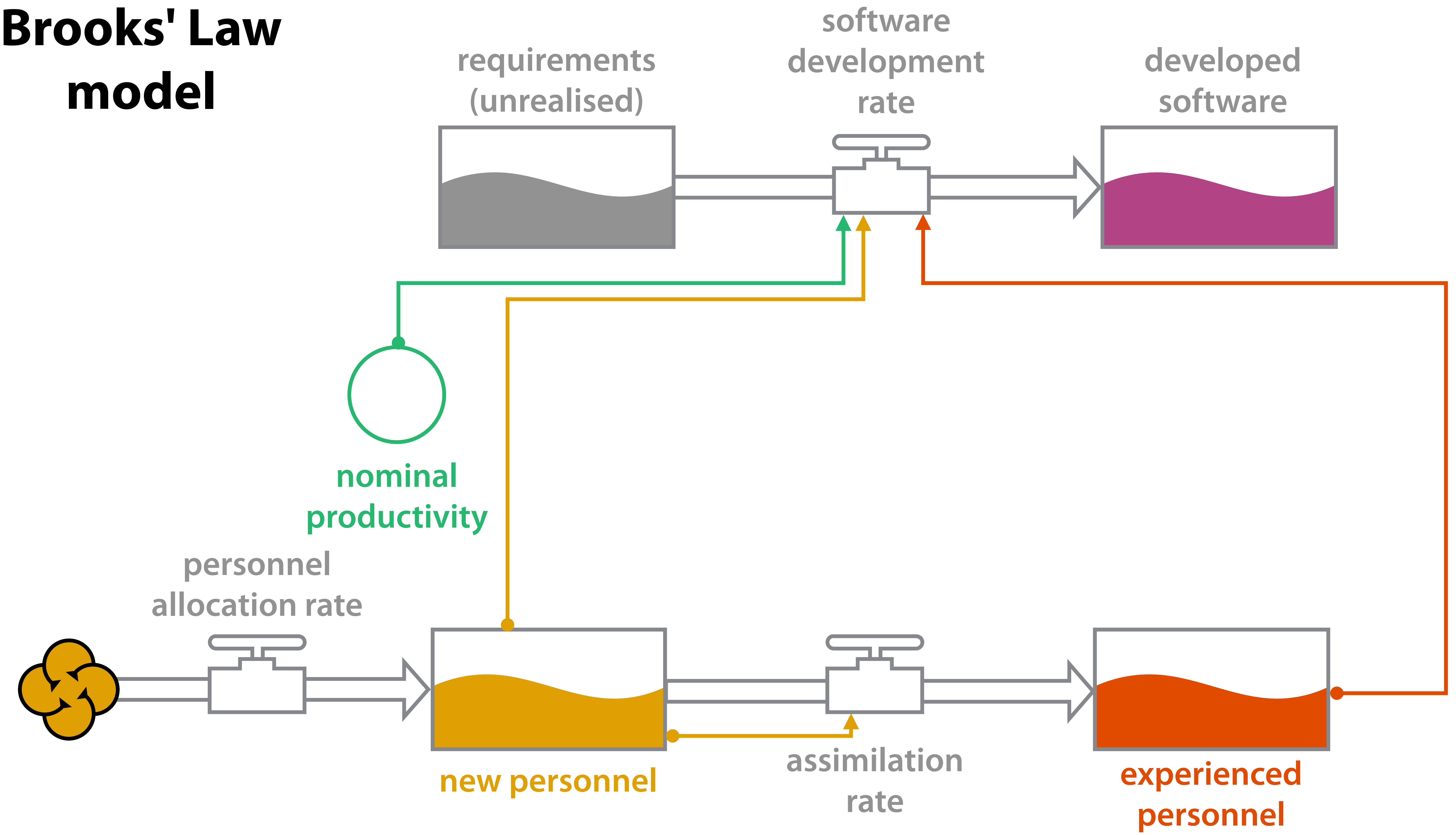
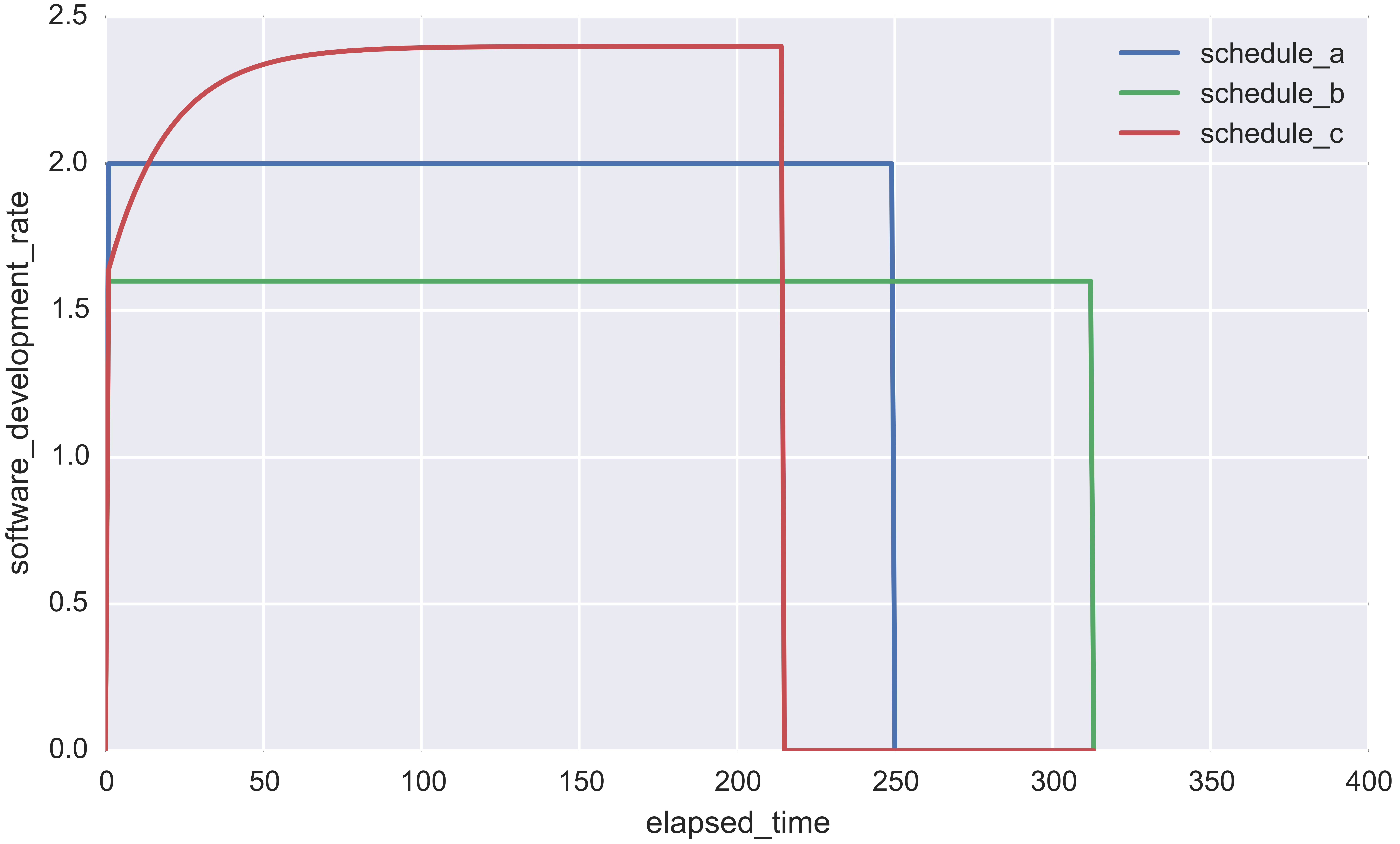
0.5
0.0
software_development_rate
0
50
100
150
200
250
300
350
400
elapsed_time
schedule_a
schedule_b
Schedule B
500 function points
20 inexperienced personnel
0.08 fps/person/day
313 days to completion

Brooks' Law model





2.5
2.0
1.5
1.0
0.5
0.0
0
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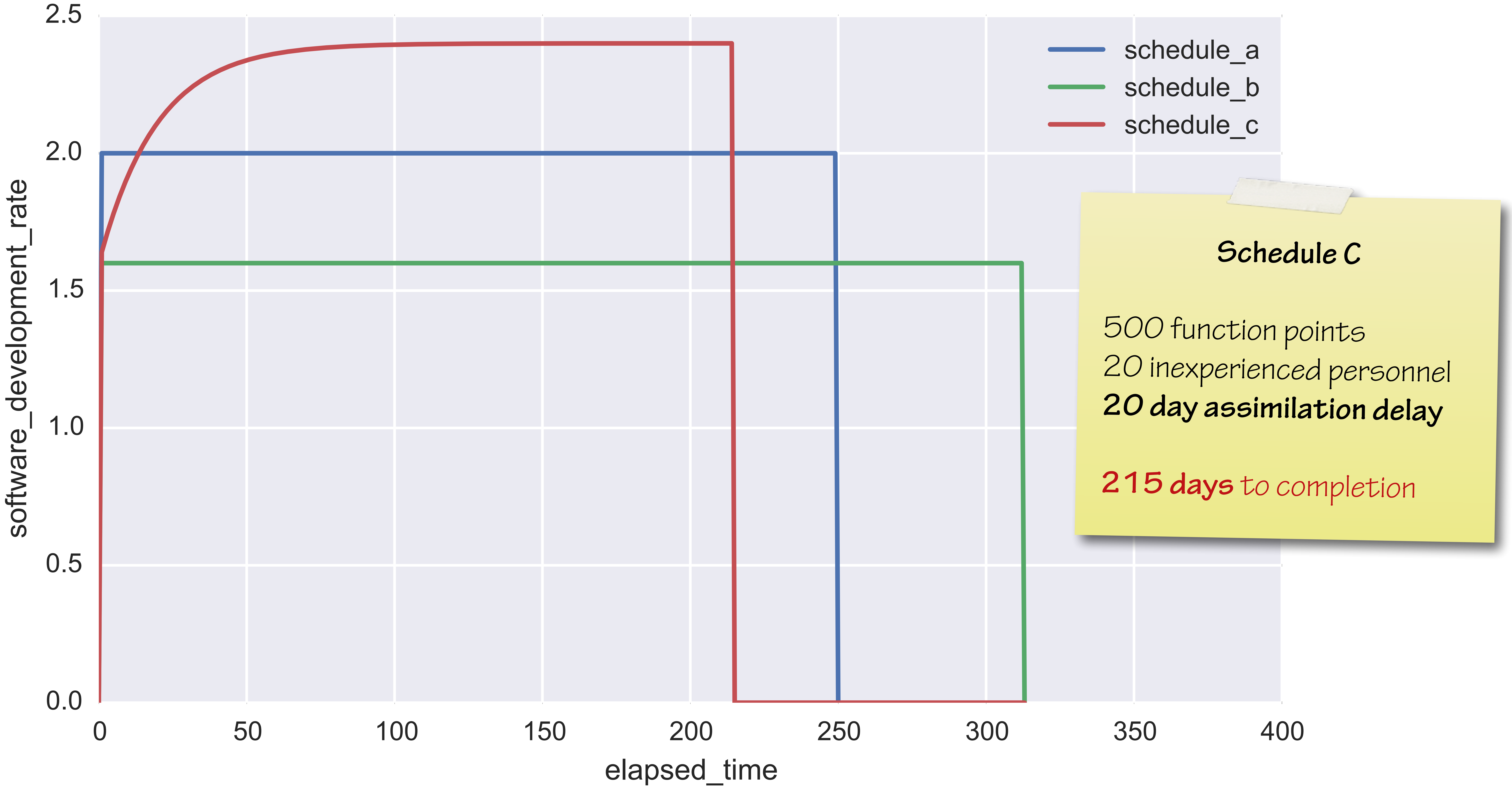
100
150
200
250
300
350
400
elapsed_time
software_development_rate
schedule_a
schedule_b
schedule_c


2.5
2.0
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1.0
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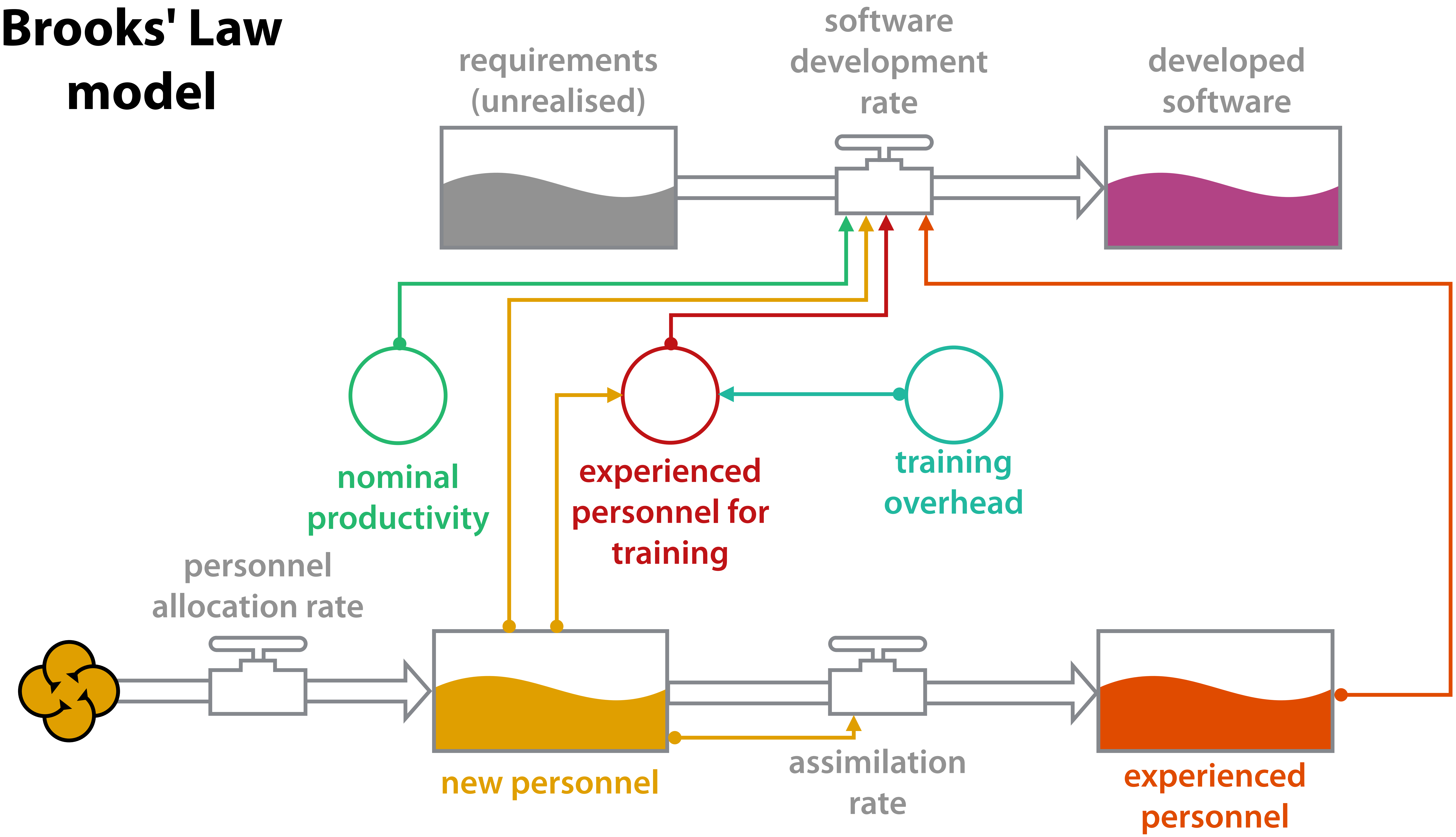
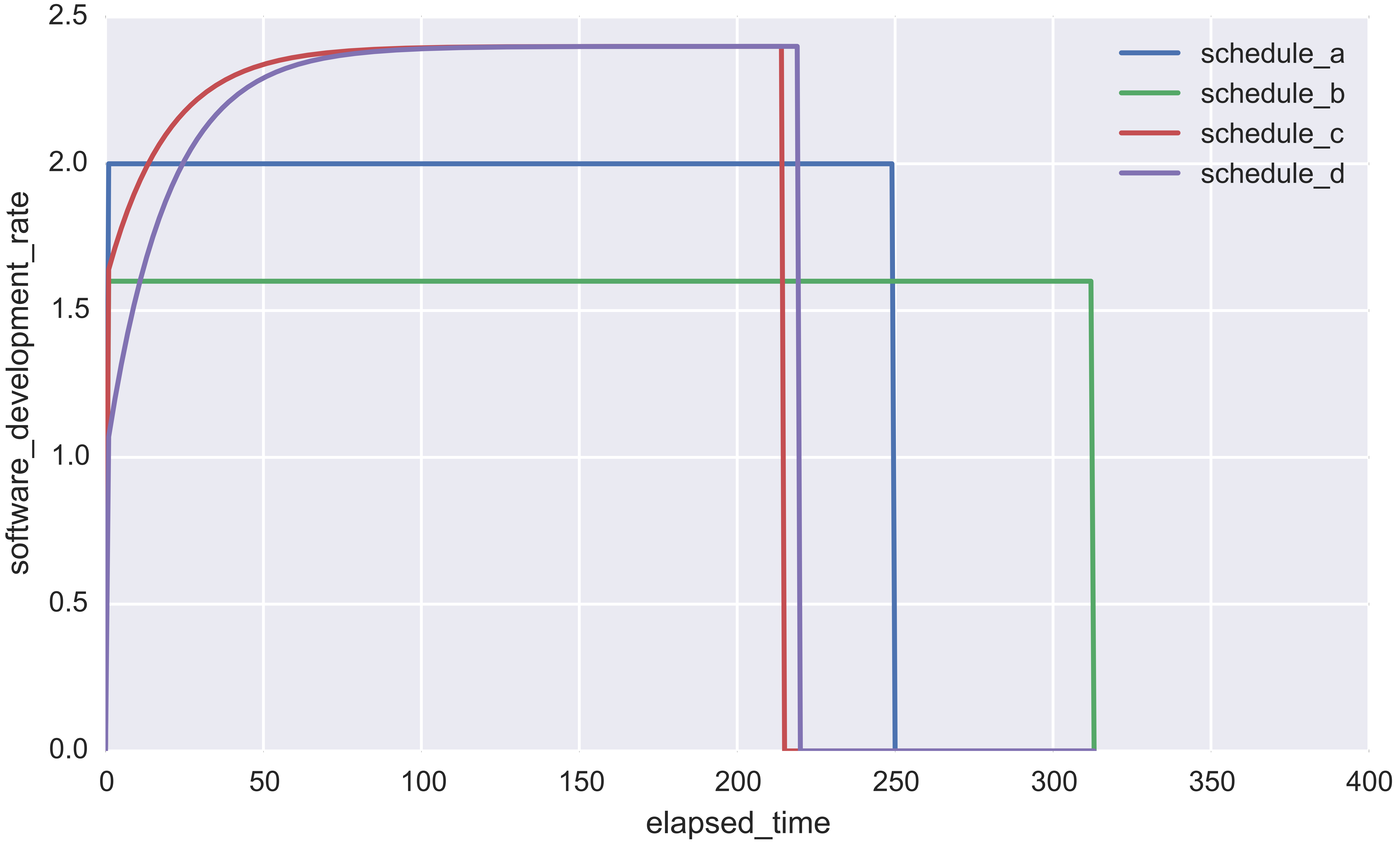
0.0
software_development_rate
0
50
100
150
200
250
300
350
400
elapsed_time
schedule_a
schedule_b
schedule_c
Schedule C
500 function points
20 inexperienced personnel
20 day assimilation delay
215 days to completion

Brooks' Law model




schedule_a
schedule_b
schedule_c
schedule_d
software_development_rate
elapsed_time
2.5
2.0
1.5
1.0
0.5
0.0
0
50
100
150
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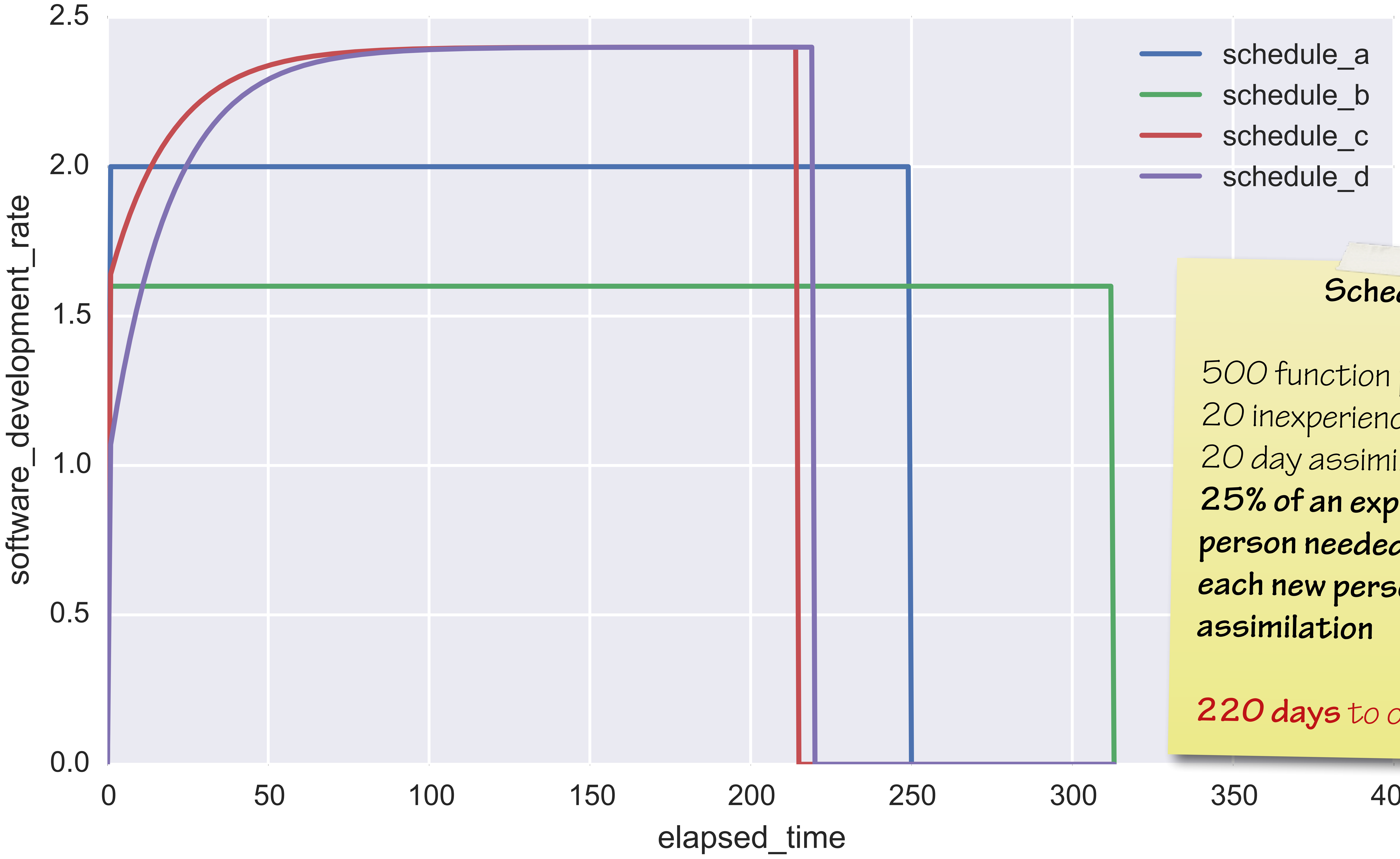
400

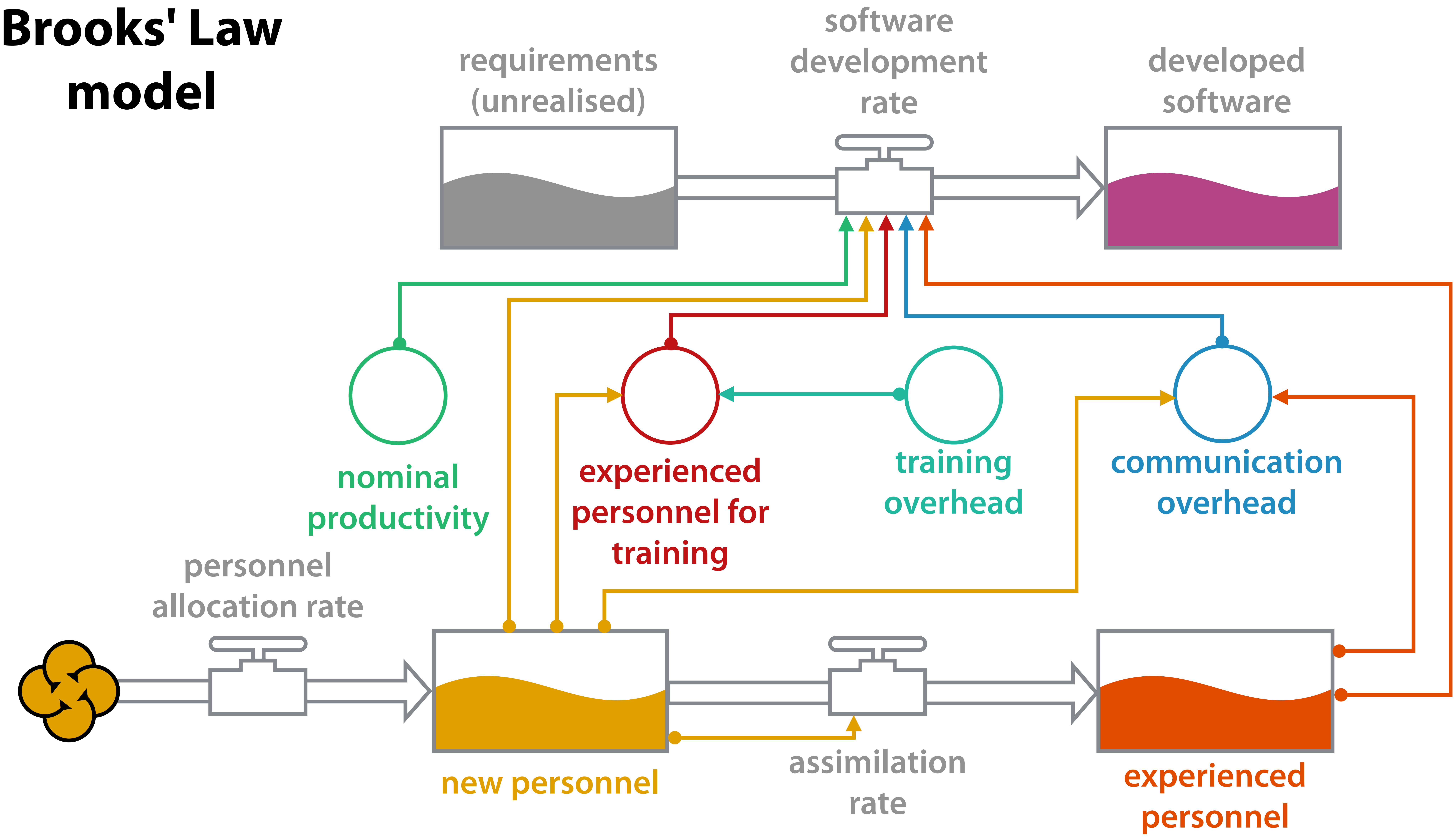


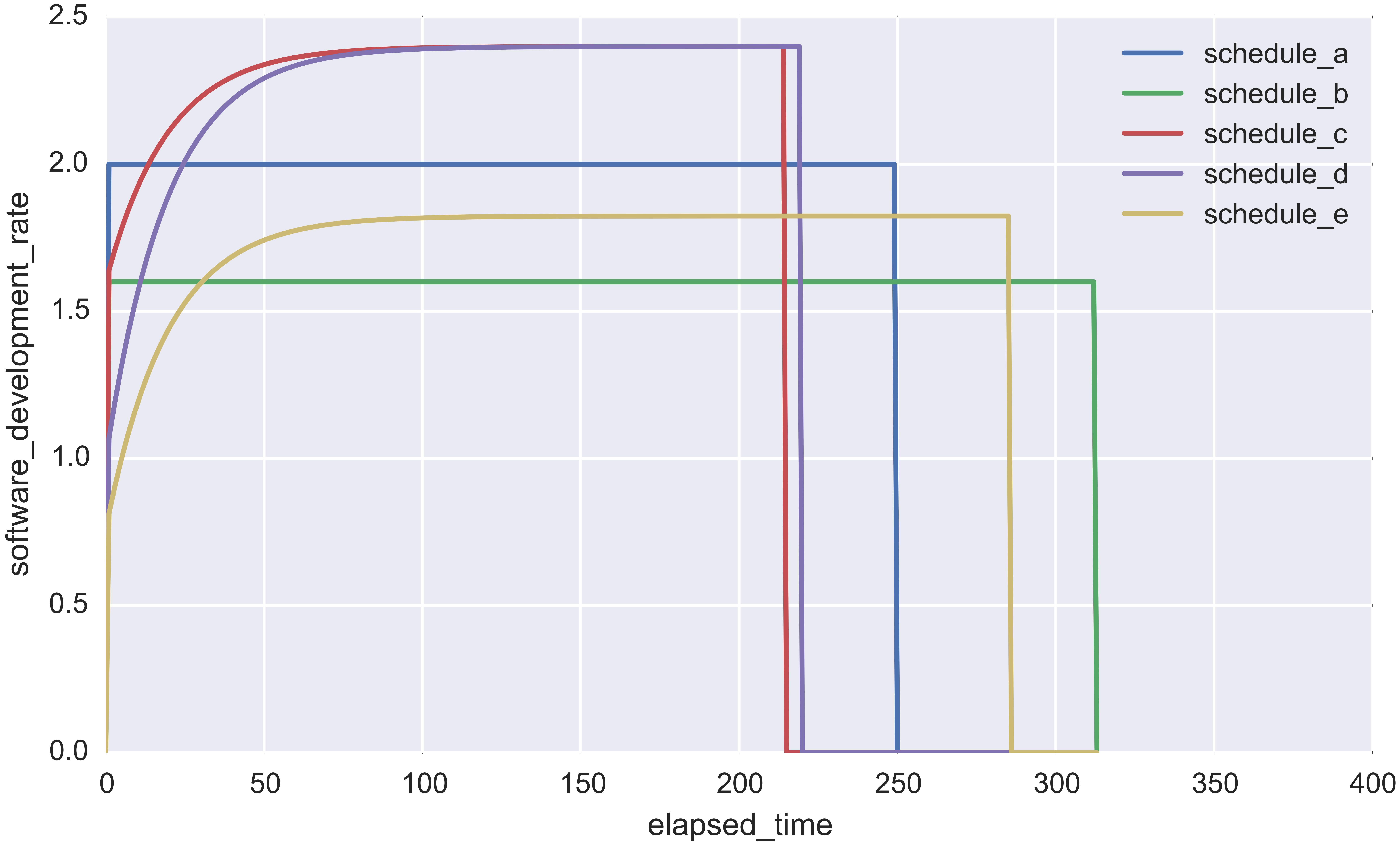
Schedule D

500 function points
20 inexperienced personnel
20 day assimilation delay
25% of an experienced person needed for training each new person during assimilation

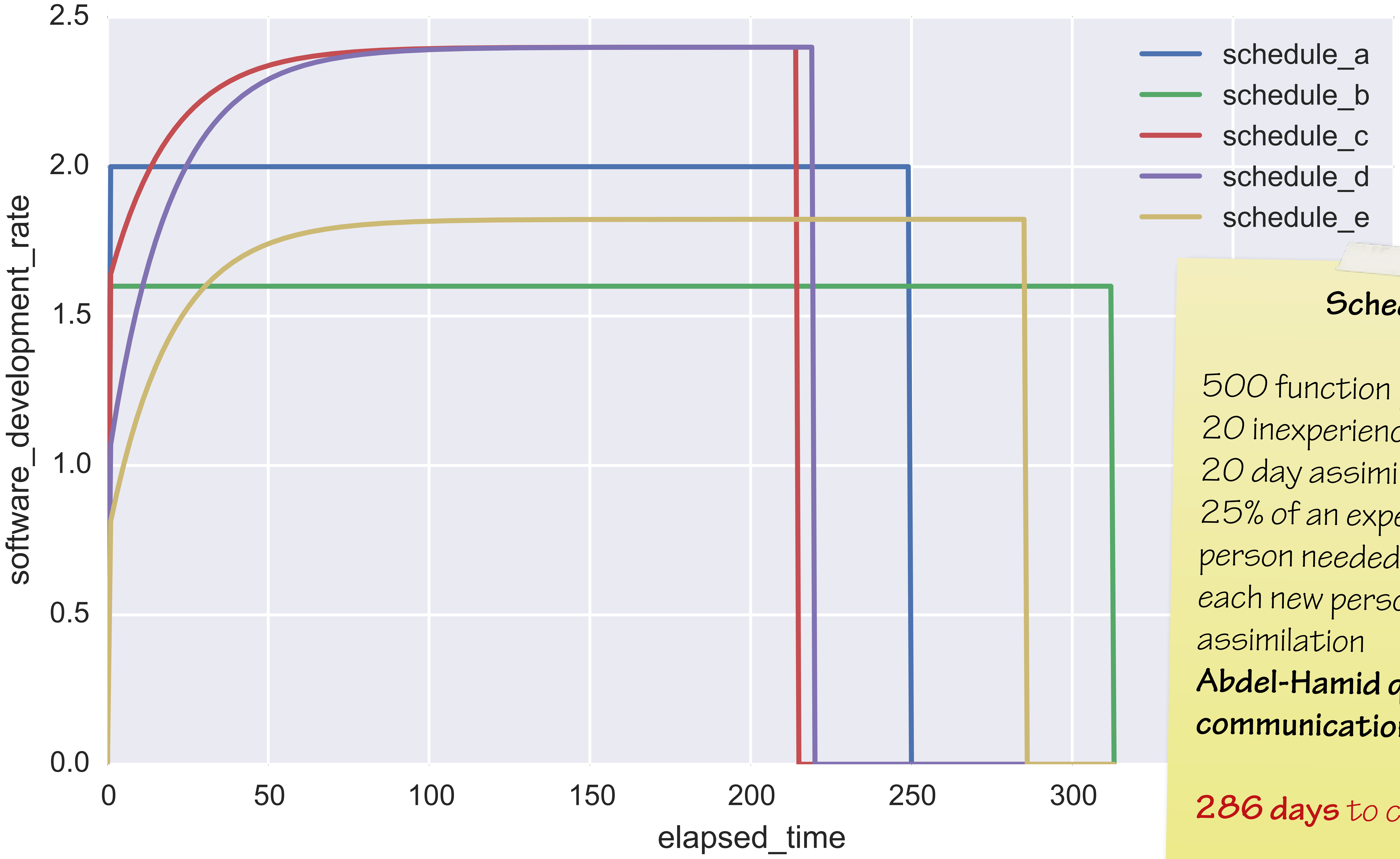
220 days to completion

Brooks' Law model





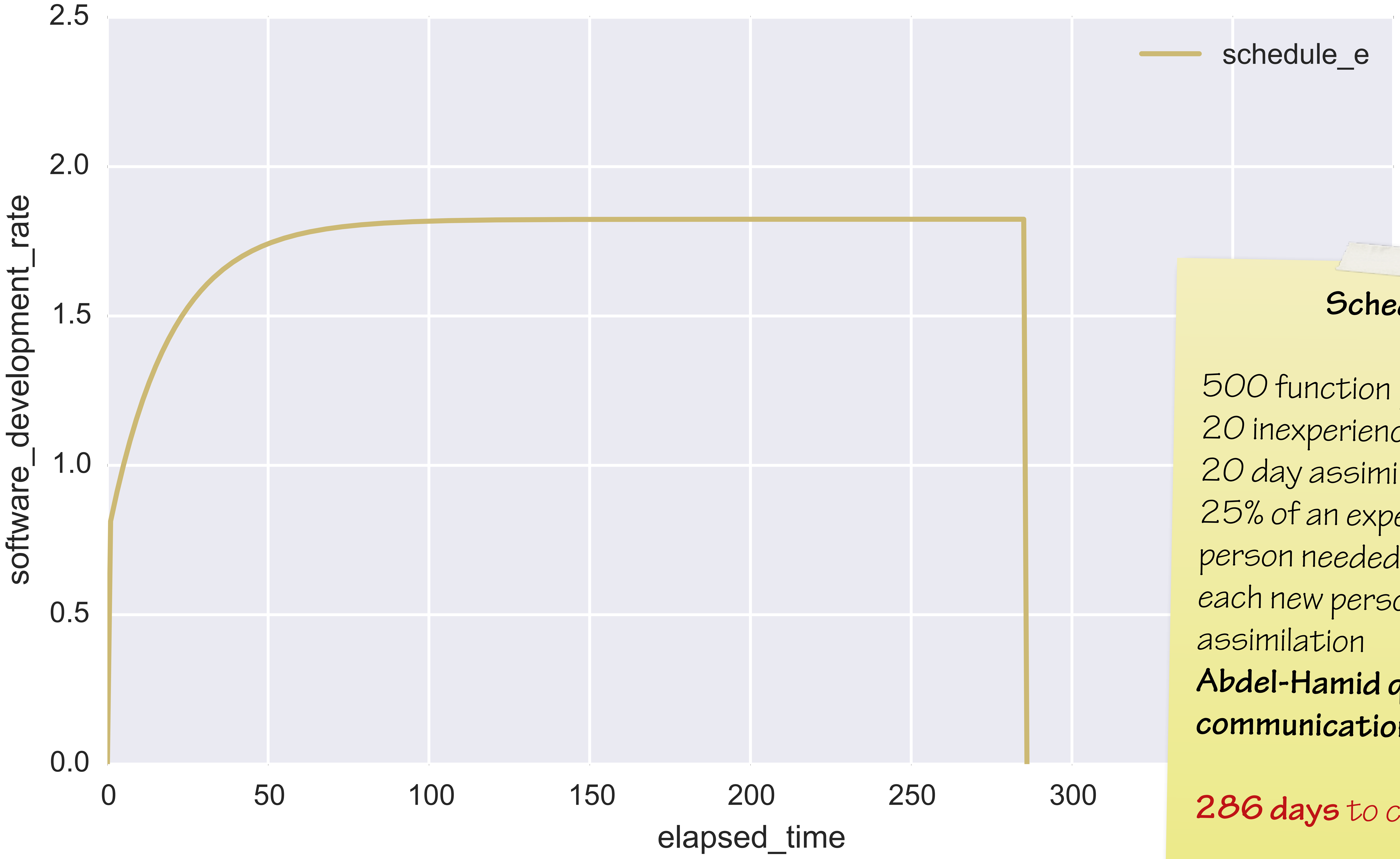
software_development_rate
elapsed_time
0.0
0.5
1.0
1.5
2.0
2.5
0
50
100
150
200
250
300
350
400
schedule_a
schedule_b
schedule_c
schedule_d
schedule_e



Schedule E

500 function points
20 inexperienced personnel
20 day assimilation delay
25% of an experienced person needed for training each new person during assimilation
Abdel-Hamid quadratic communication overhead

286 days to completion



Schedule E

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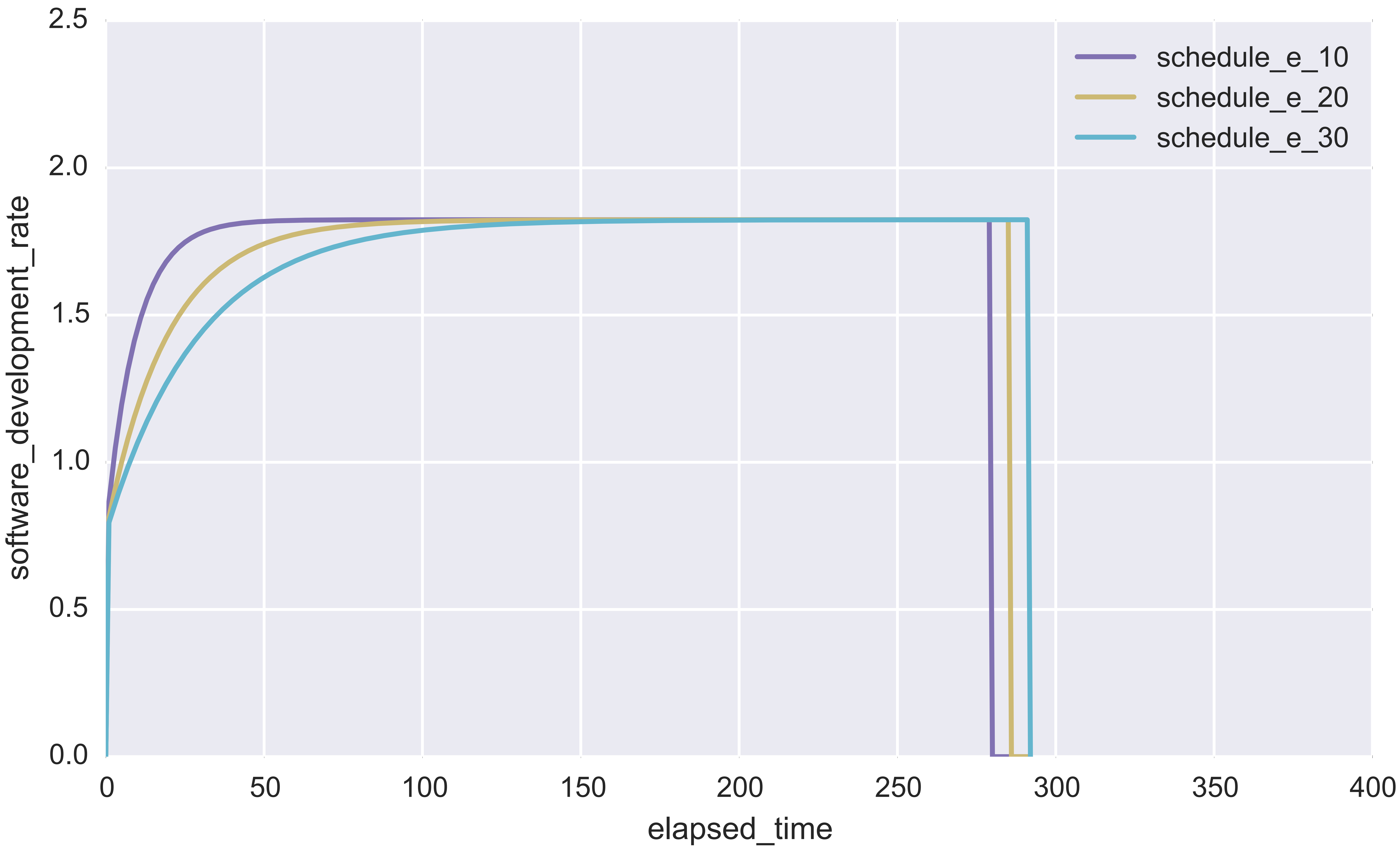
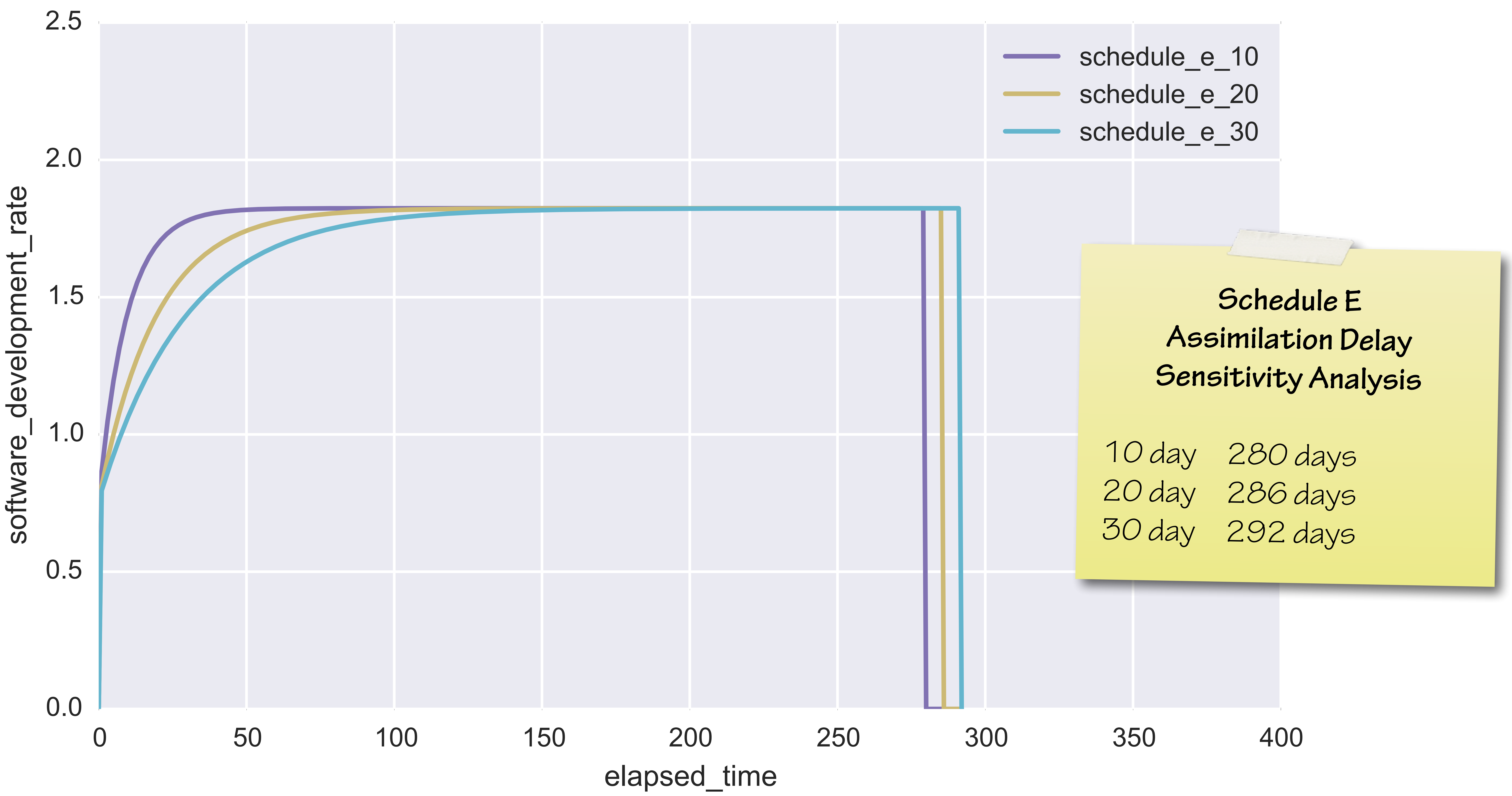
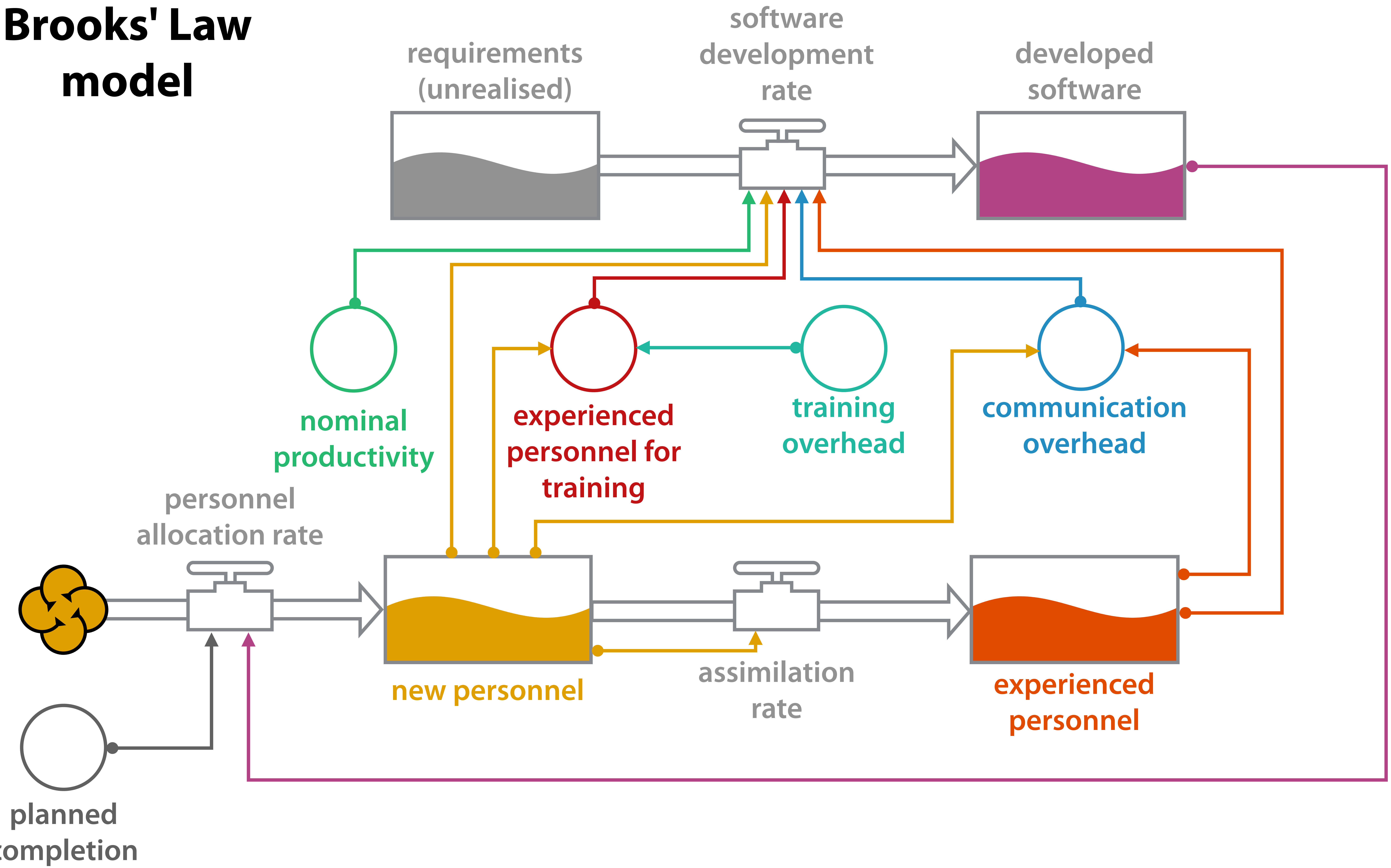
286 days to completion



schedule_e_10
schedule_e_20
schedule_e_30
software_development_rate
elapsed_time
0.0
0.5
1.0
1.5
2.0
2.5
0
50
100
150
200
250
300
350
400


2.5
2.0
1.5
1.0
0.5
0.0
software_development_rate
0
50
100
150
200
250
300
350
400
elapsed_time
schedule_e_10
schedule_e_20
schedule_e_30
Schedule E
Assimilation Delay
Sensitivity Analysis
10 day 280 days
20 day 286 days
30 day 292 days

Brooks' Law model

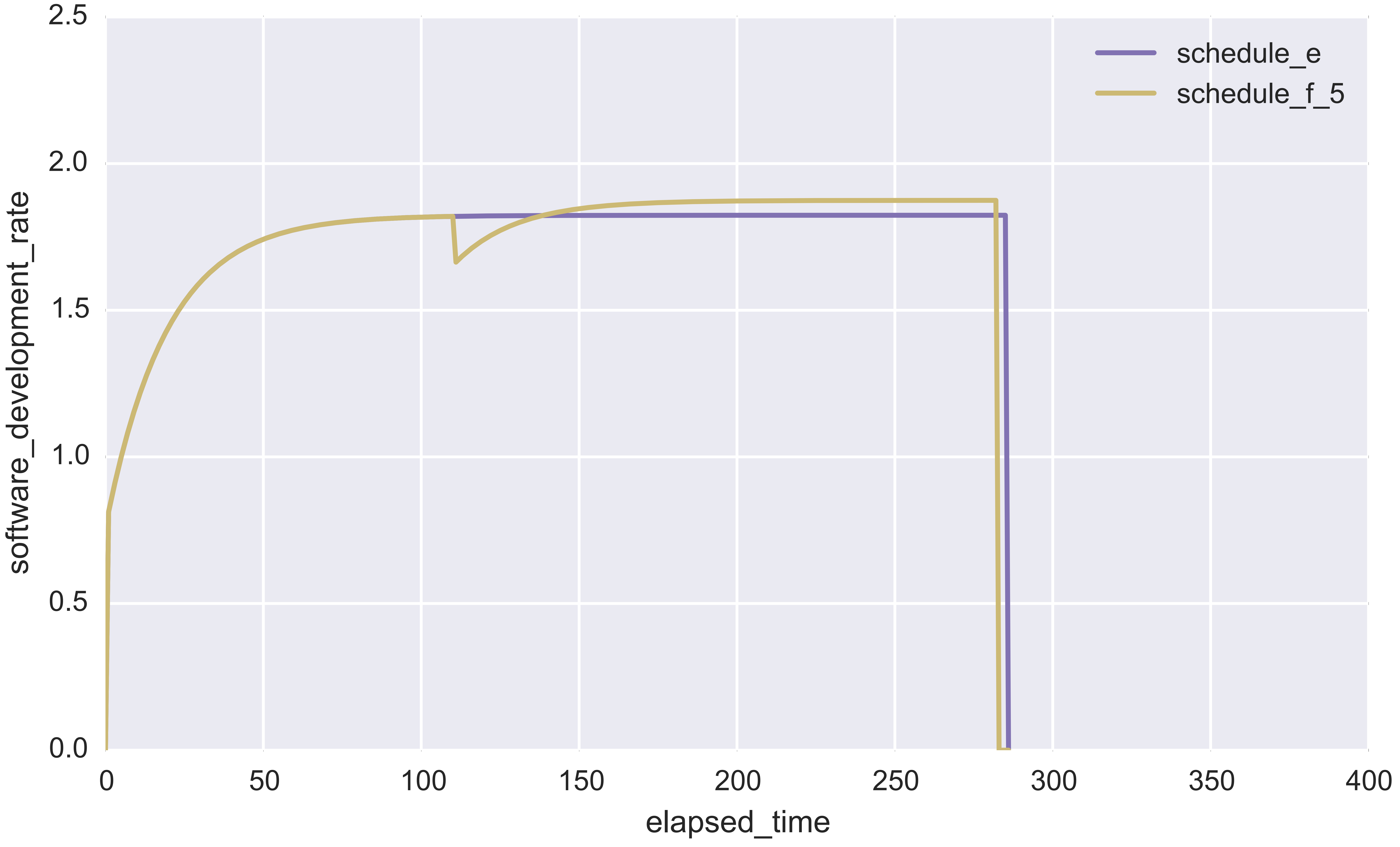


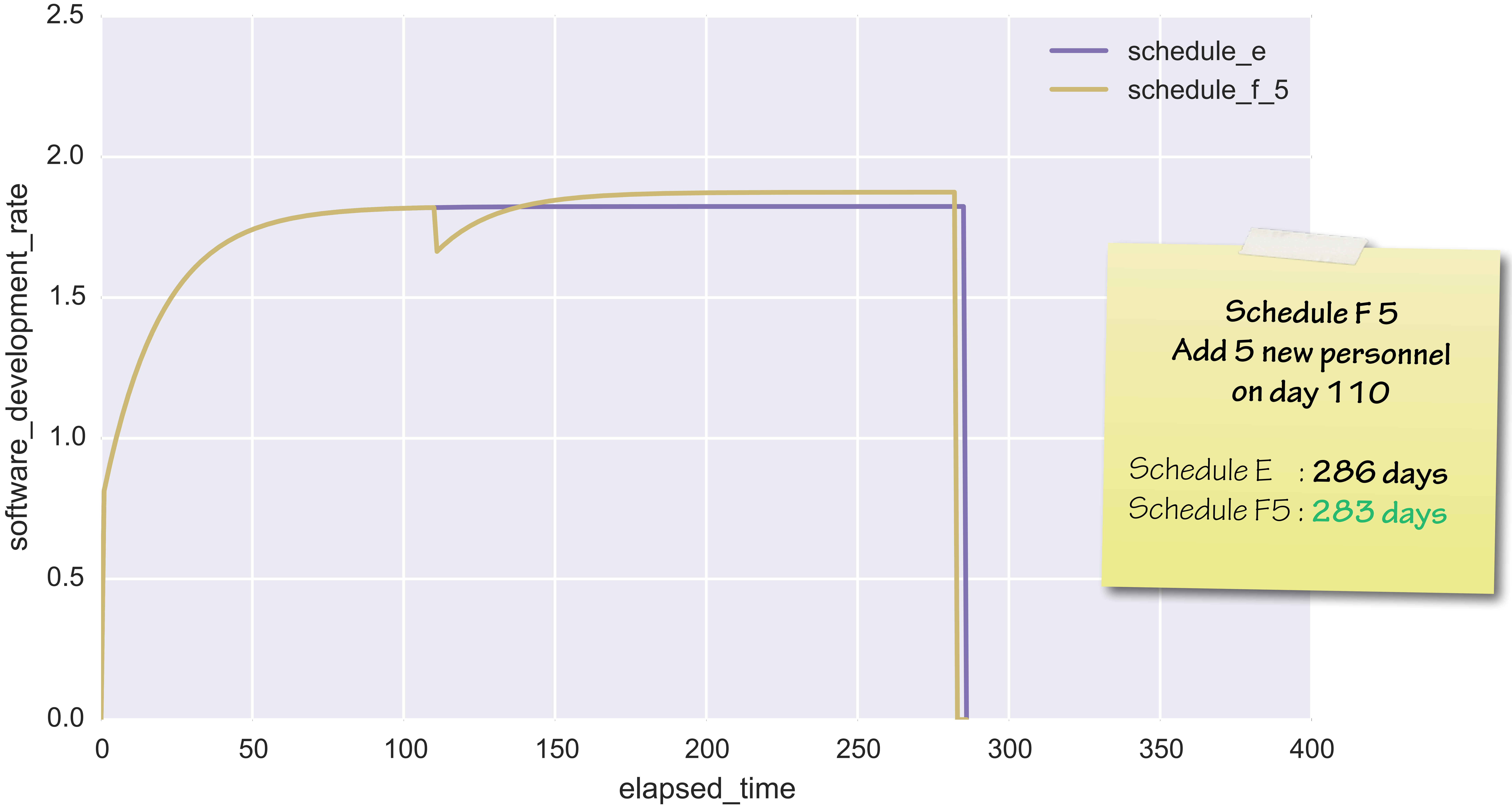
schedule_e.py

```python
import brooks.communication


def initial():
    """Configure the initial model state."""
    return dict(
        step_duration_days=1,
        num_function_points_requirements=500,
        num_function_points_developed=0,
        num_new_personnel=20,
        num_experienced_personnel=0,
        personnel_allocation_rate=0,
        personnel_assimilation_rate=0,
        assimilation_delay_days=20,
        nominal_productivity=0.1,
        new_productivity_weight=0.8,
        experienced_productivity_weight=1.2,
        training_overhead_proportion=0.25,
        communication_overhead_function=brooks.communication.quadratic_overhead_proportion,
        software_development_rate=None,
    )


def intervene(step_number, elapsed_time, state):
    """Intervene in the current step before the main simulation step is executed."""
    return state


def is_complete(step_number, elapsed_time_seconds, state):
    """Determine whether the simulation should end."""
    return state.num_function_points_developed >= state.num_function_points_requirements


def complete(step_number, elapsed_time_seconds, state):
    """Finalise the simulation state for the last recorded step."""
    state.software_development_rate = 0
    return state
```

schedule_f_5.py

```python
import brooks.communication


def initial():
    """Configure the initial model state."""
    return dict(
        step_duration_days=1,
        num_function_points_requirements=500,
        num_function_points_developed=0,
        num_new_personnel=20,
        num_experienced_personnel=0,
        personnel_allocation_rate=0,
        personnel_assimilation_rate=0,
        assimilation_delay_days=20,
        nominal_productivity=0.1,
        new_productivity_weight=0.8,
        experienced_productivity_weight=1.2,
        training_overhead_proportion=0.25,
        communication_overhead_function=brooks.communication.quadratic_overhead_proportion,
        software_development_rate=None,
    )


def intervene(step_number, elapsed_time, state):
    """Intervene in the current step before the main simulation step is executed."""
    if elapsed_time == 110:
        state.num_new_personnel += 5
    return state


def is_complete(step_number, elapsed_time_seconds, state):
    """Determine whether the simulation should end."""
    return state.num_function_points_developed >= state.num_function_points_requirements


def complete(step_number, elapsed_time_seconds, state):
    """Finalise the simulation state for the last recorded step."""
    state.software_development_rate = 0
    return state
```

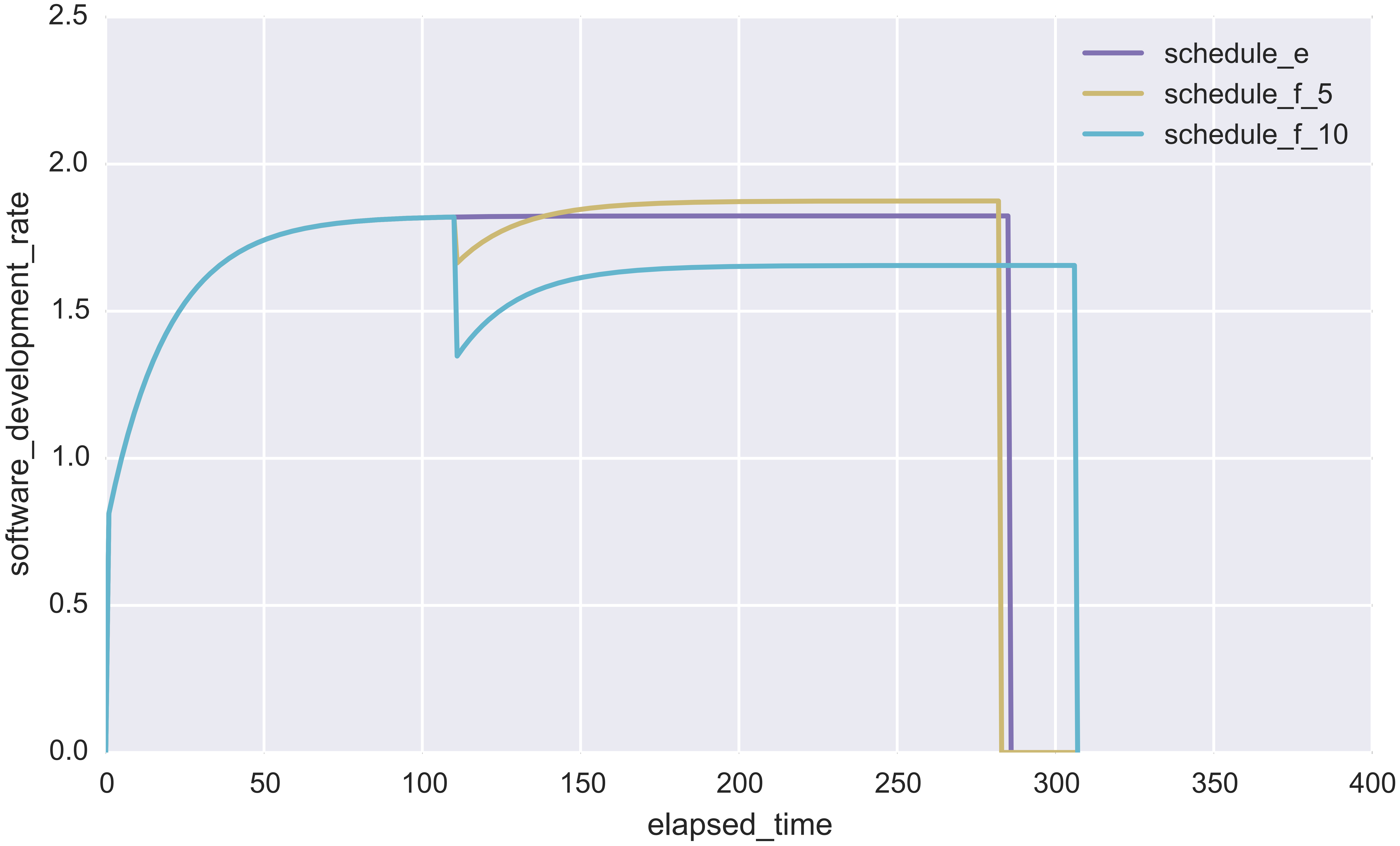

schedule_e
schedule_f_5
software_development_rate
elapsed_time
0.0
0.5
1.0
1.5
2.0
2.5
0
50
100
150
200
250
300
350
400



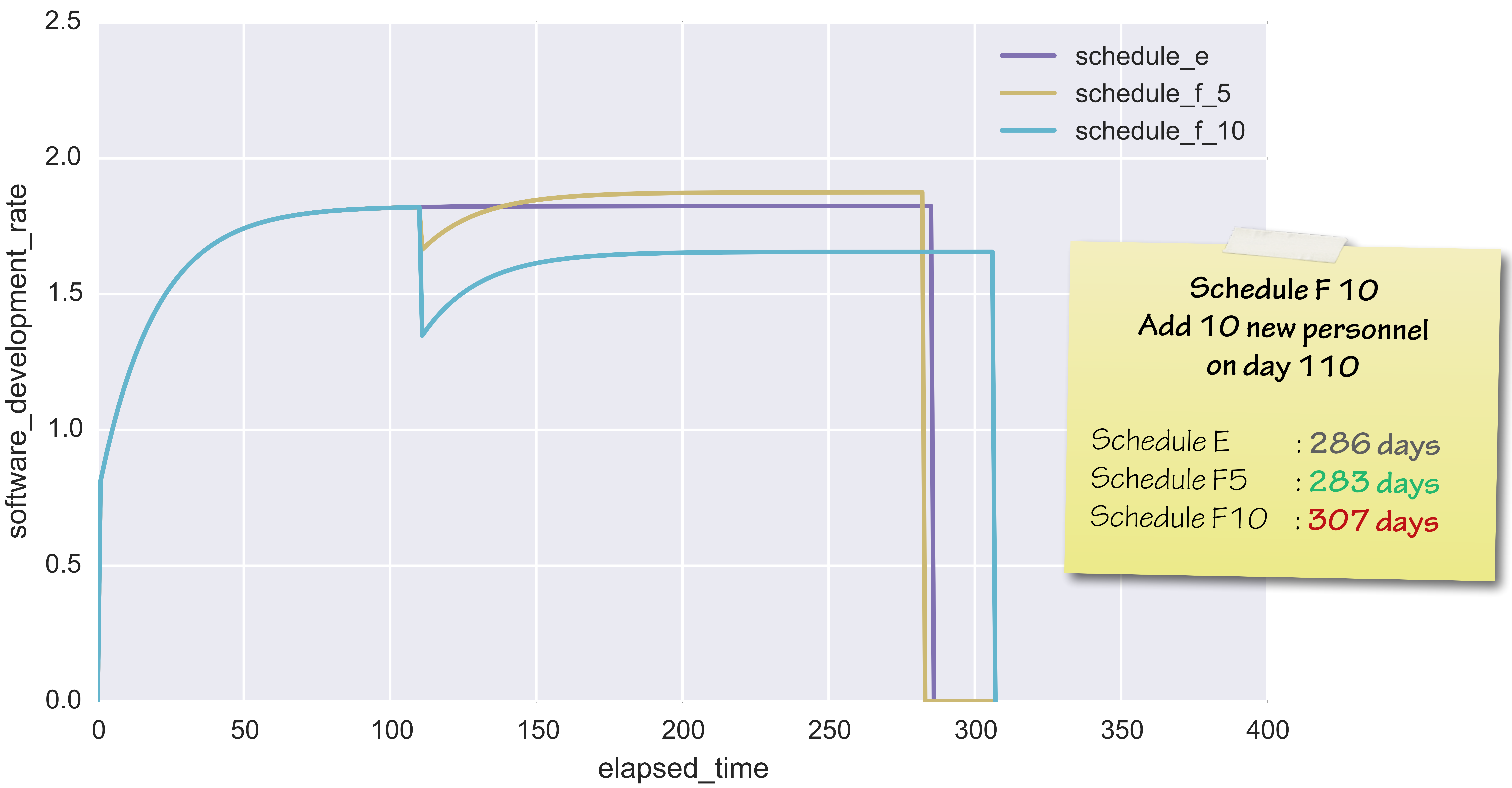
2.5
2.0
1.5
1.0
0.5
0.0
software_development_rate
0
50
100
150
200
250
300
350
400
elapsed_time
schedule_e
schedule_f_5
Schedule F 5
Add 5 new personnel
on day 110
Schedule E : 286 days
Schedule F5 : 283 days

Fred Brooks was WRONG!

Actually…



schedule_e
schedule_f_5
schedule_f_10
software_development_rate
elapsed_time
0.0
0.5
1.0
1.5
2.0
2.5
0
50
100
150
200
250
300
350
400


2.5
2.0
1.5
1.0
0.5
0.0
software_development_rate
0
50
100
150
200
250
300
350
400
elapsed_time
schedule_e
schedule_f_5
schedule_f_10
Schedule F 10
Add 10 new personnel
on day 110
Schedule E : 286 days
Schedule F5 : 283 days
Schedule F10 : 307 days

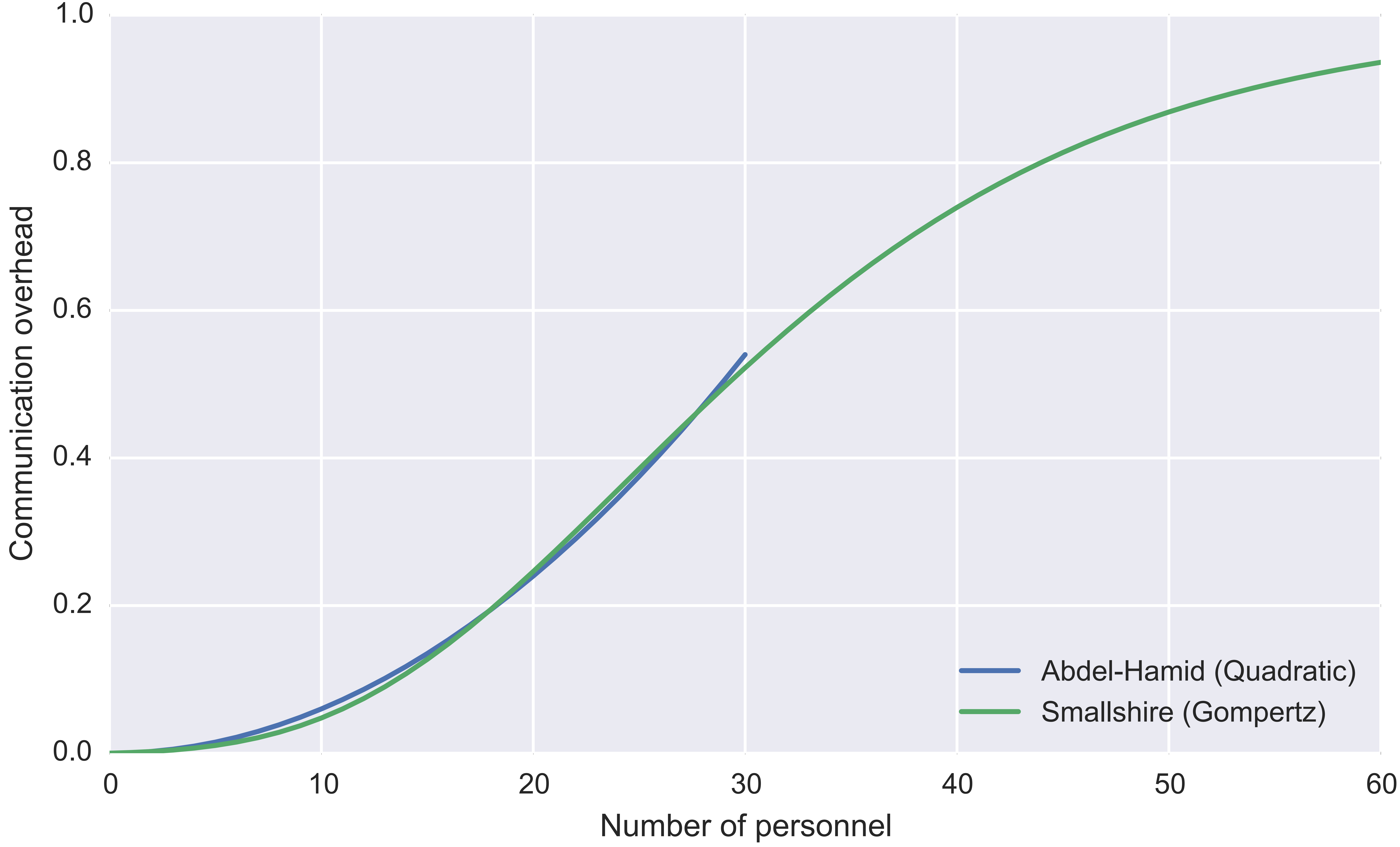
Fred Brooks was RIGHT!

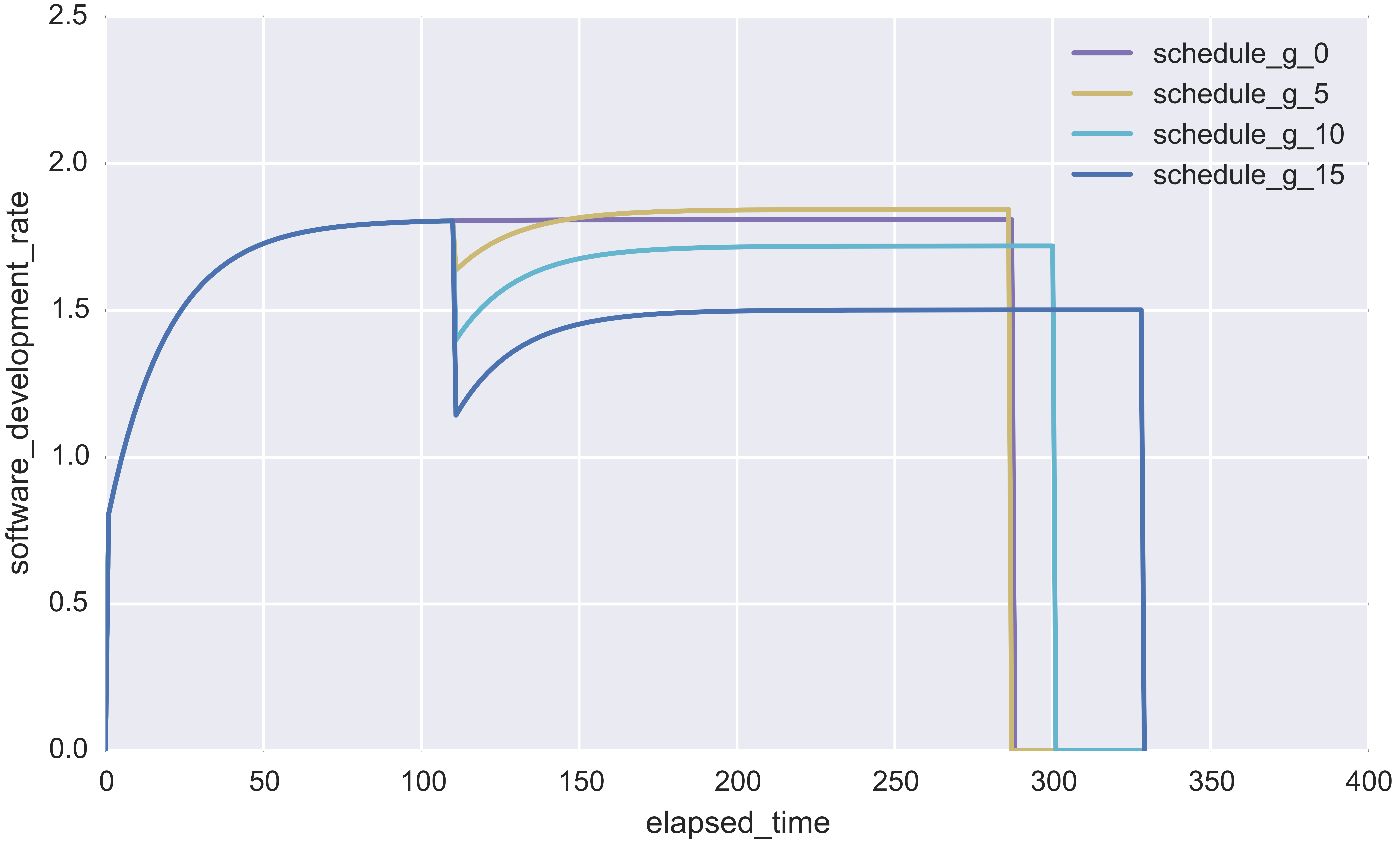
```
ValueError: Communication overhead
proportion personnel number 34.9 out
of range
```

```
ValueError: Communication overhead proportion personnel number 34.9 out of range
```

Model limitations

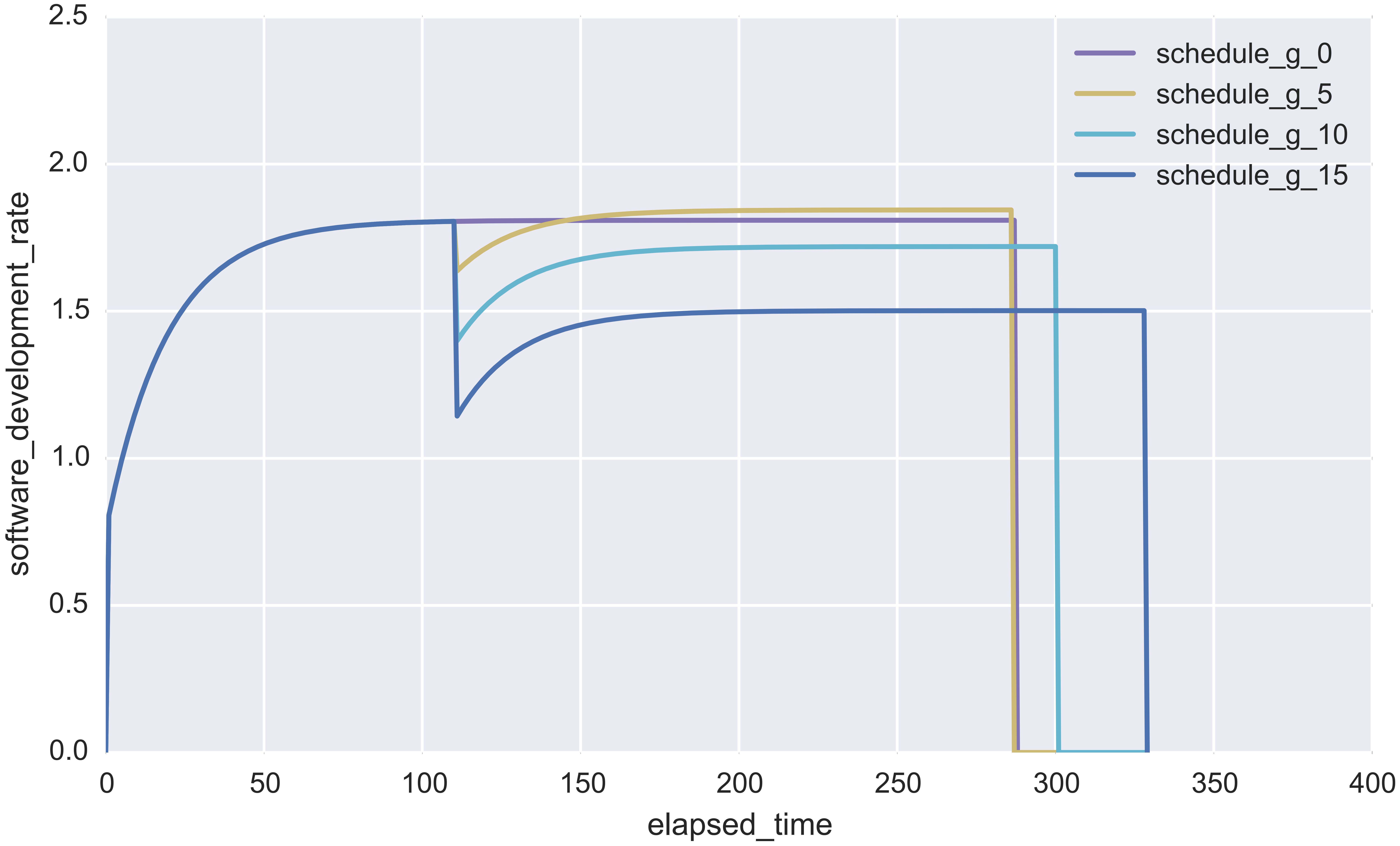
Prevent extrapolation outside reasonable bounds!


1.0
0.8
0.6
0.4
0.2
0.0
Communication overhead
0
10
20
30
40
50
60
Number of personnel
Abdel-Hamid (Quadratic)
Smallshire (Gompertz)

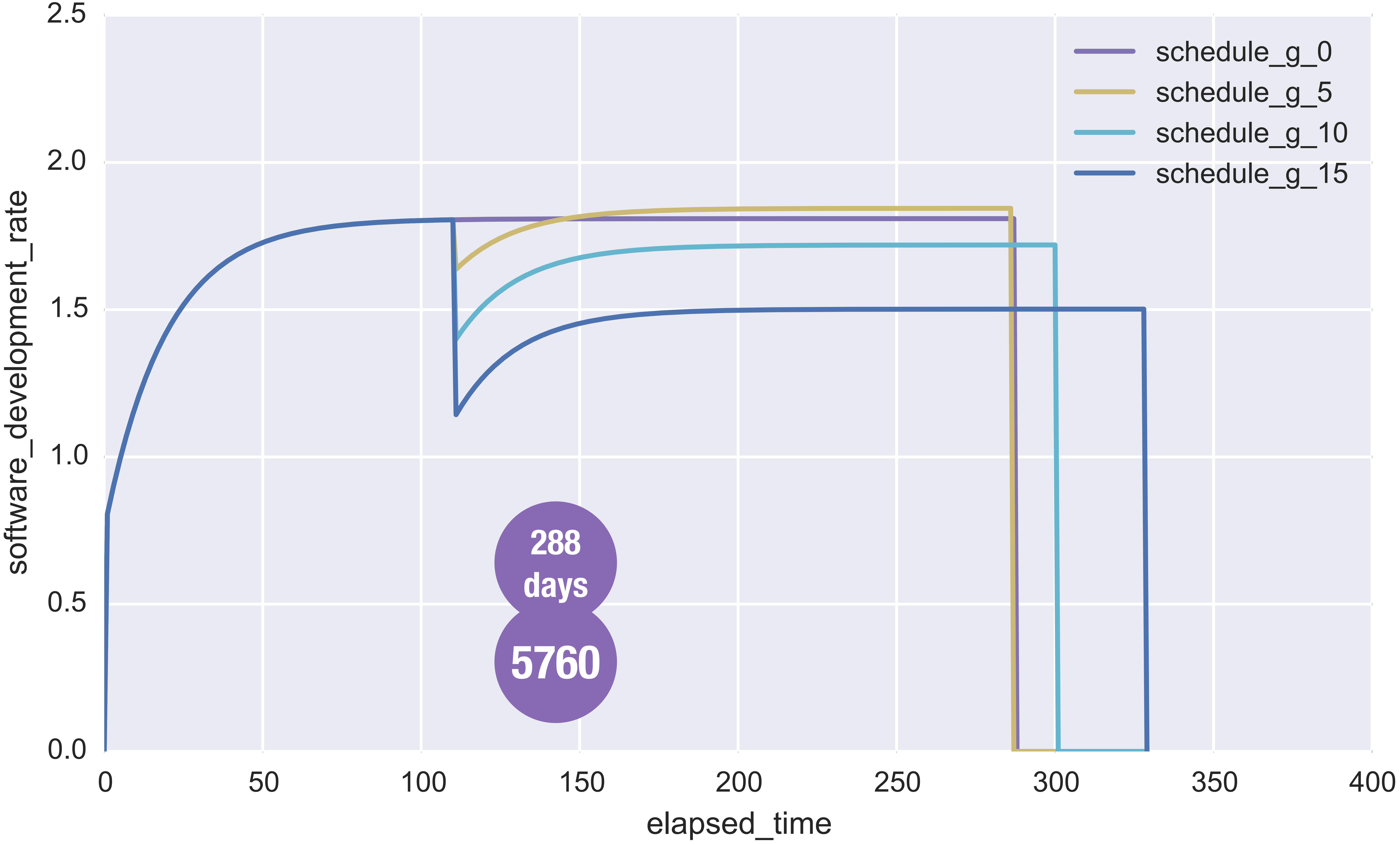


2.5
2.0
1.5
1.0
0.5
0.0
software_development_rate
0
50
100
150
200
250
300
350
400
elapsed_time
schedule_g_0
schedule_g_5
schedule_g_10
schedule_g_15

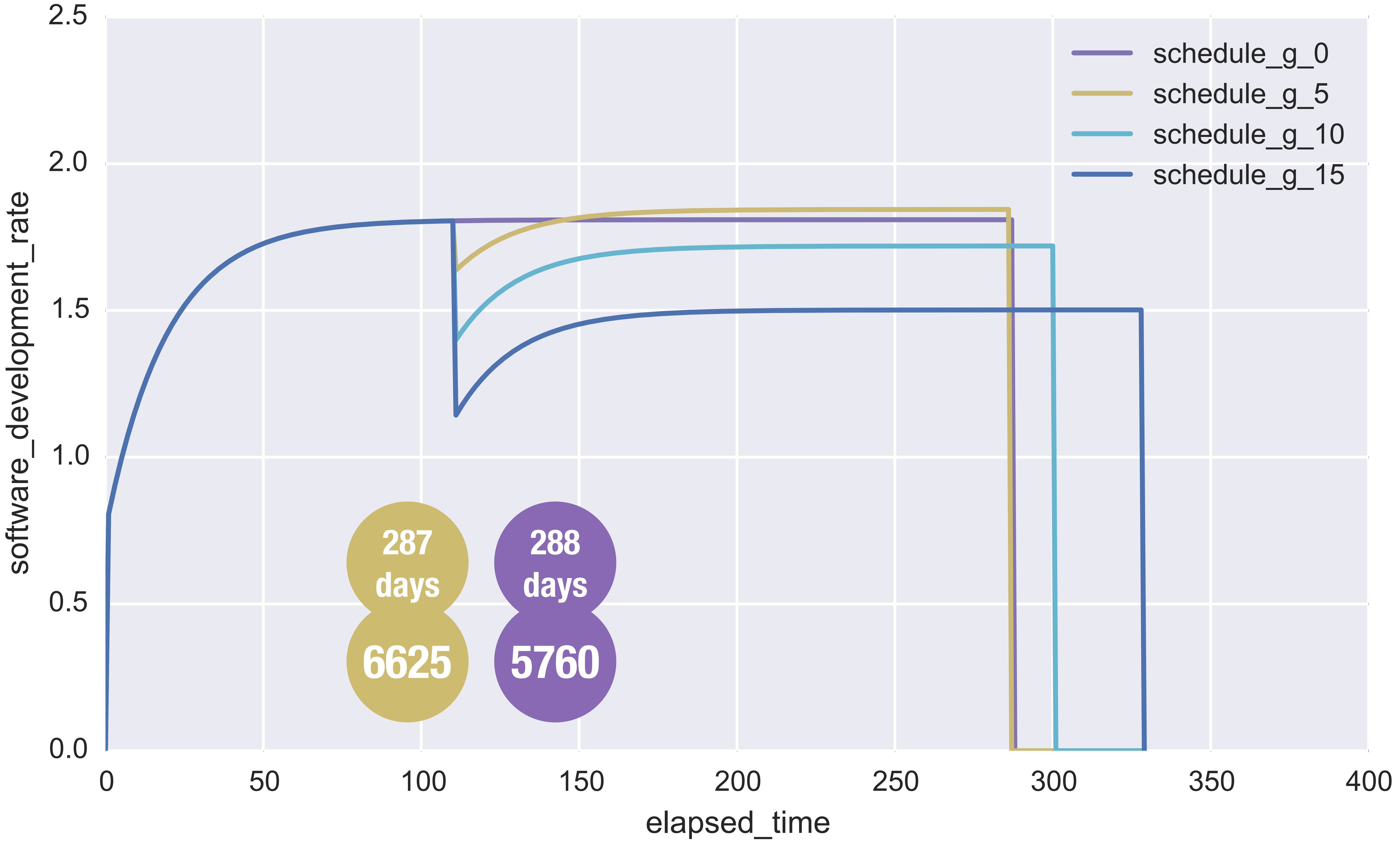
What about cost?



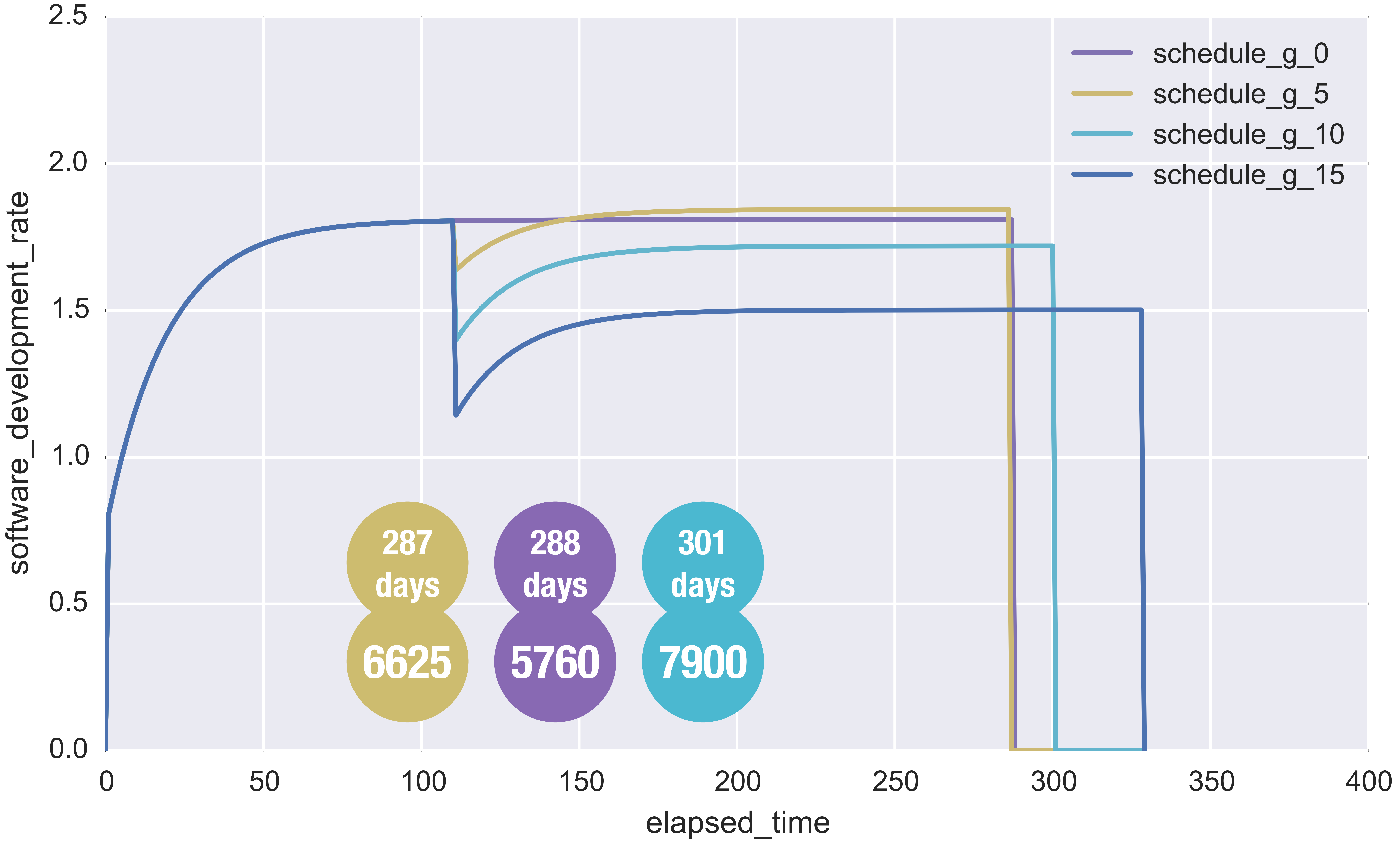
What about cost?



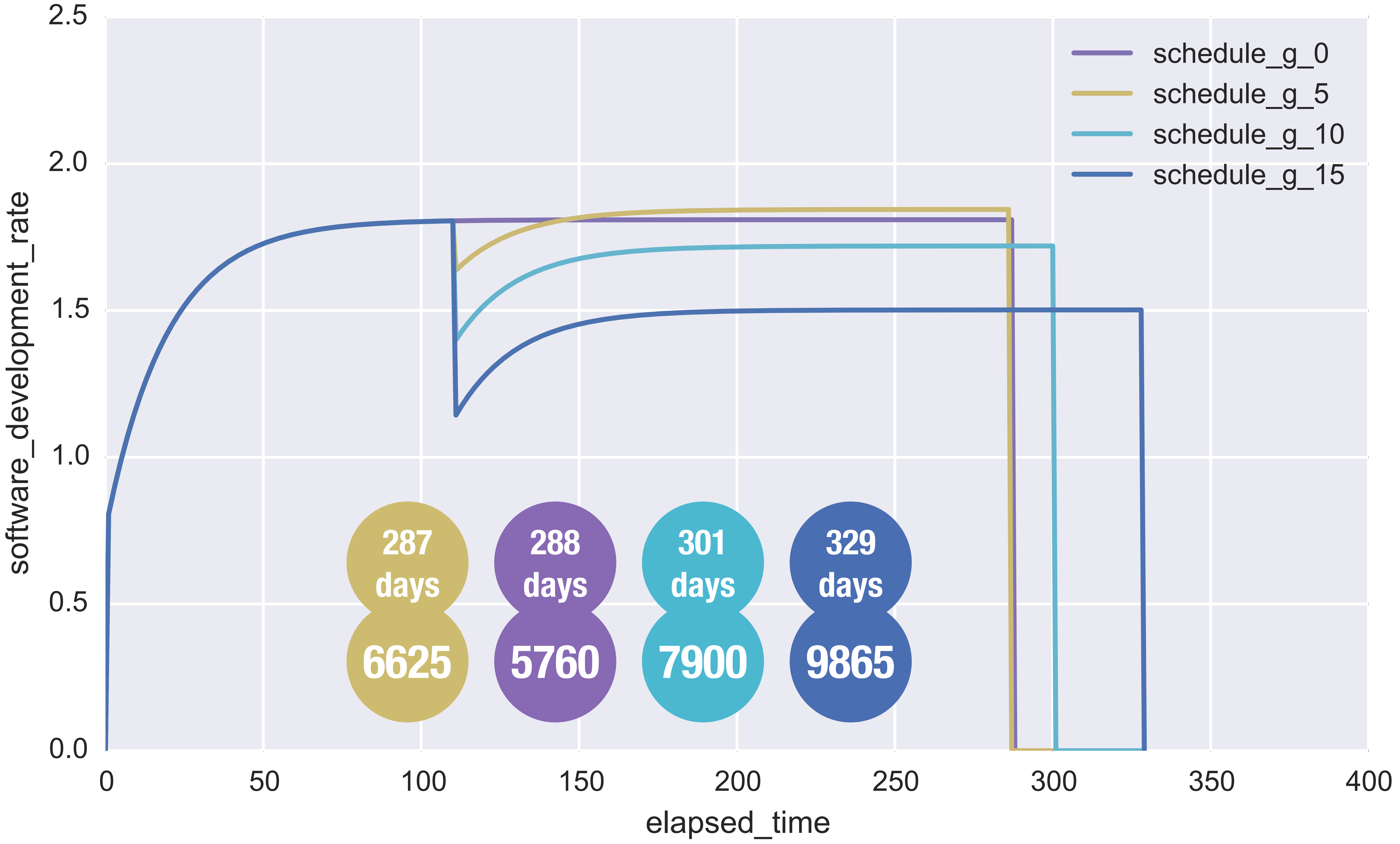
What about cost?



What about cost?



What about cost?



Modelling system growth
How many people work on your system?

1

Predicting project progress
How many people should work on your system?

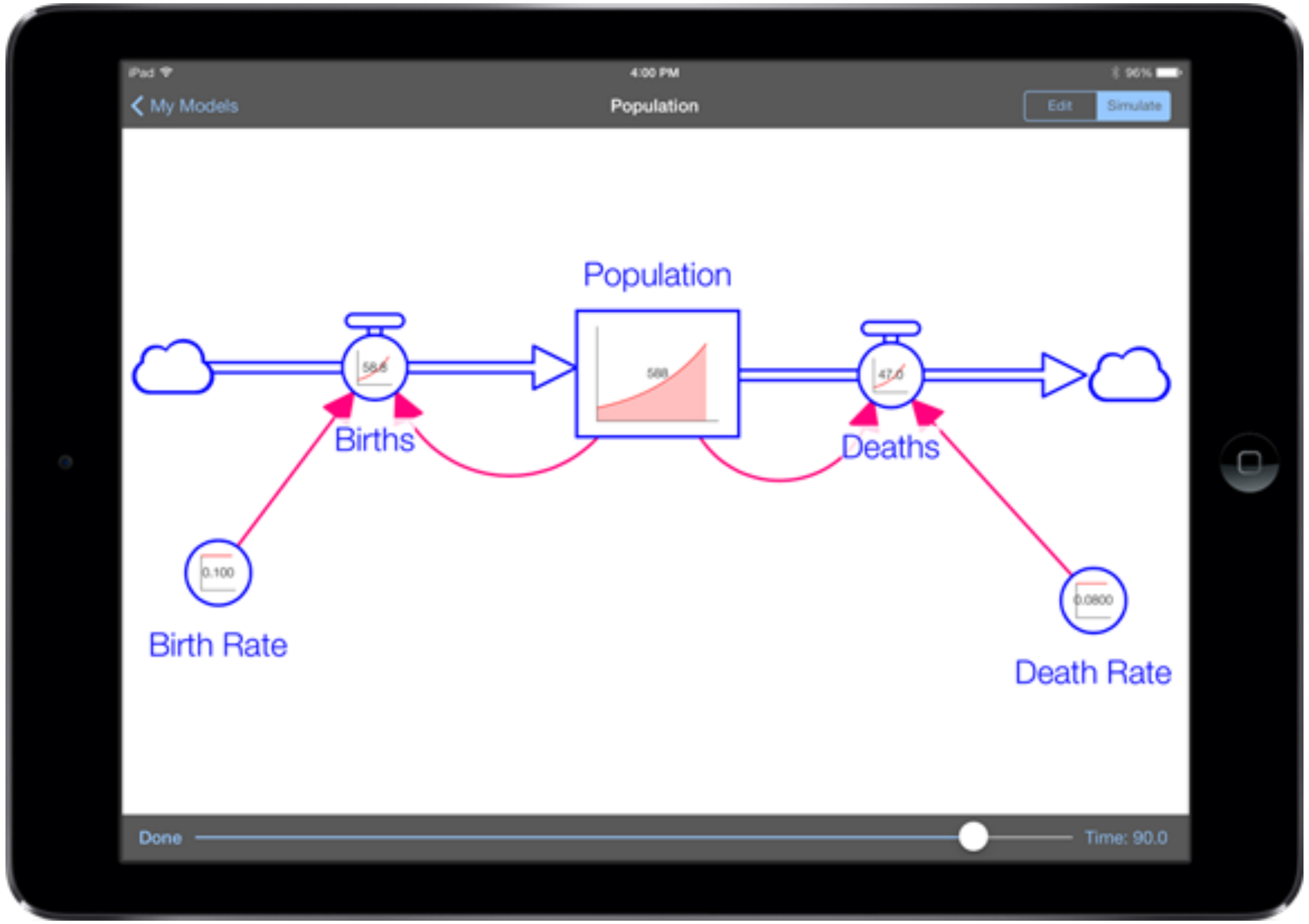
2

Software process dynamics
How can you construct models and run simulations?

3

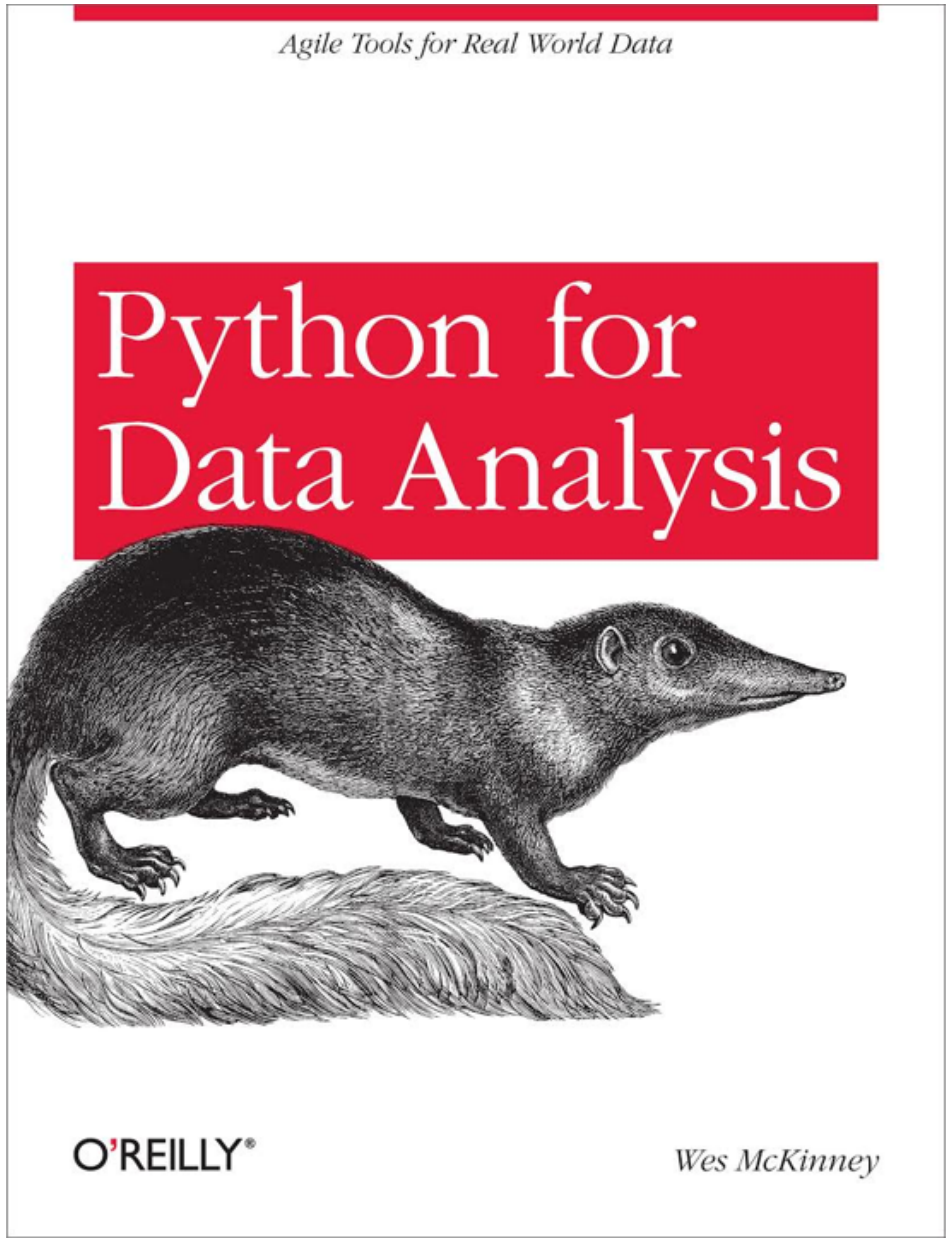
Simulation Tools

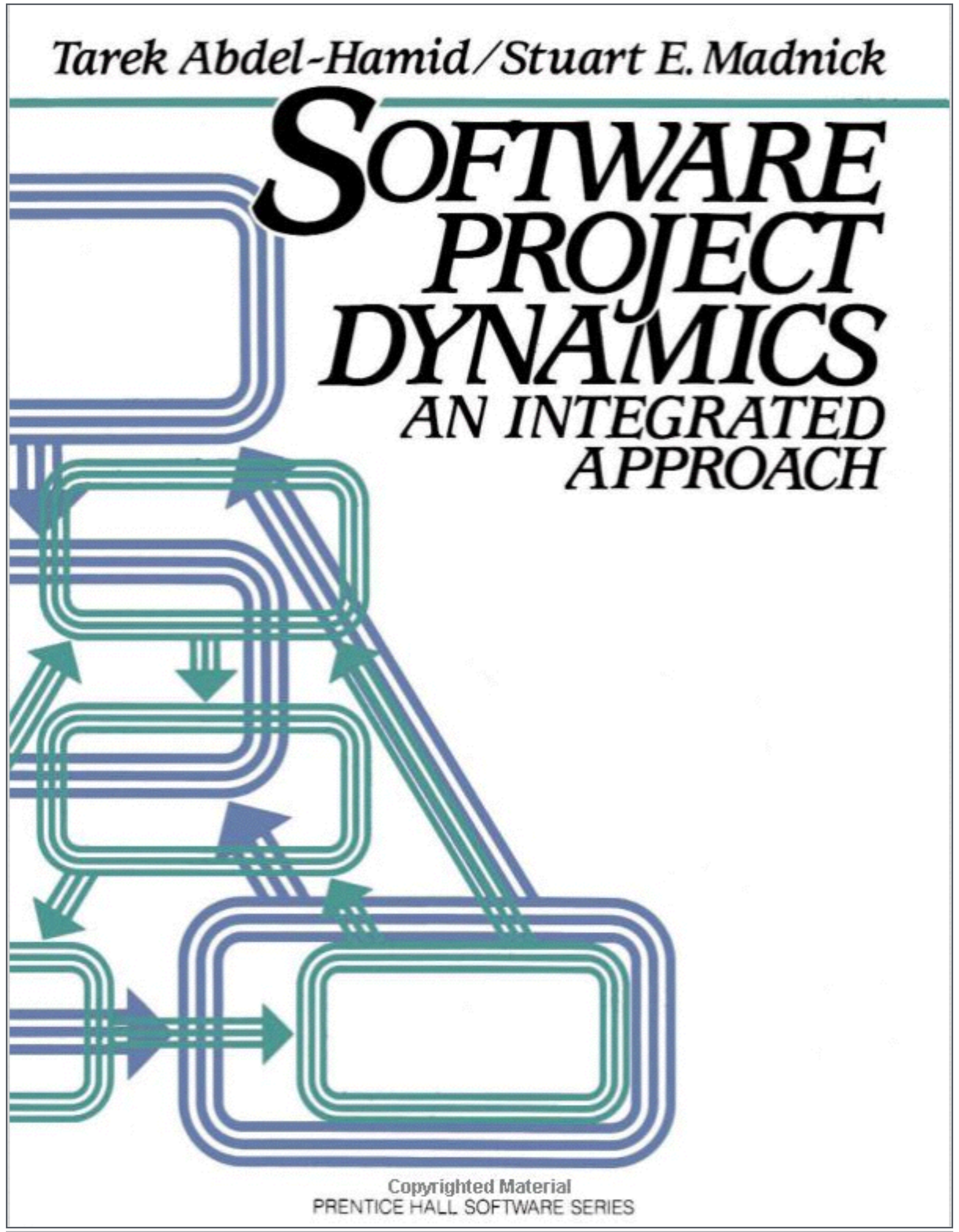
- iThink / Stella
- Vensim
- Excel
- PowerSim
- Simile
- *etc*

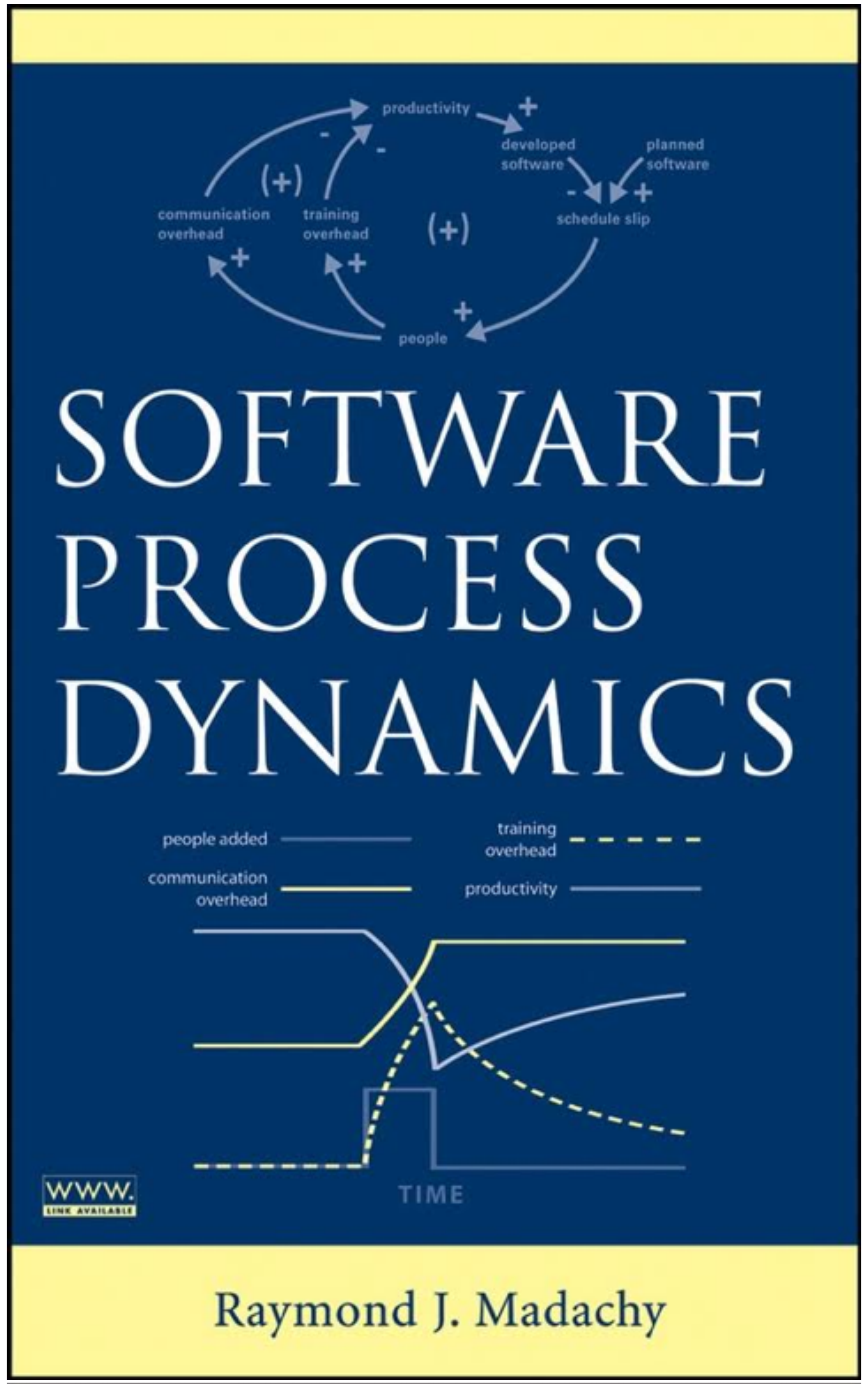


Program it yourself

- Python
- Matplotlib (charting)
- Pandas (tables, time-series)
- Numpy (fast numerics)




Tarek Abdel-Hamid/Stuart E. Madnick
SOFTWARE PROJECT DYNAMICS
AN INTEGRATED APPROACH
Copyrighted Material
PRENTICE HALL SOFTWARE SERIES


productivity
developed software
planned software
communication overhead
training overhead
schedule slip
people
(+)
(+)
SOFTWARE PROCESS DYNAMICS
people added
training overhead
communication overhead
productivity
TIME
Raymond J. Madachy

Model implementation

`https://github.com/sixty-north/brooks`

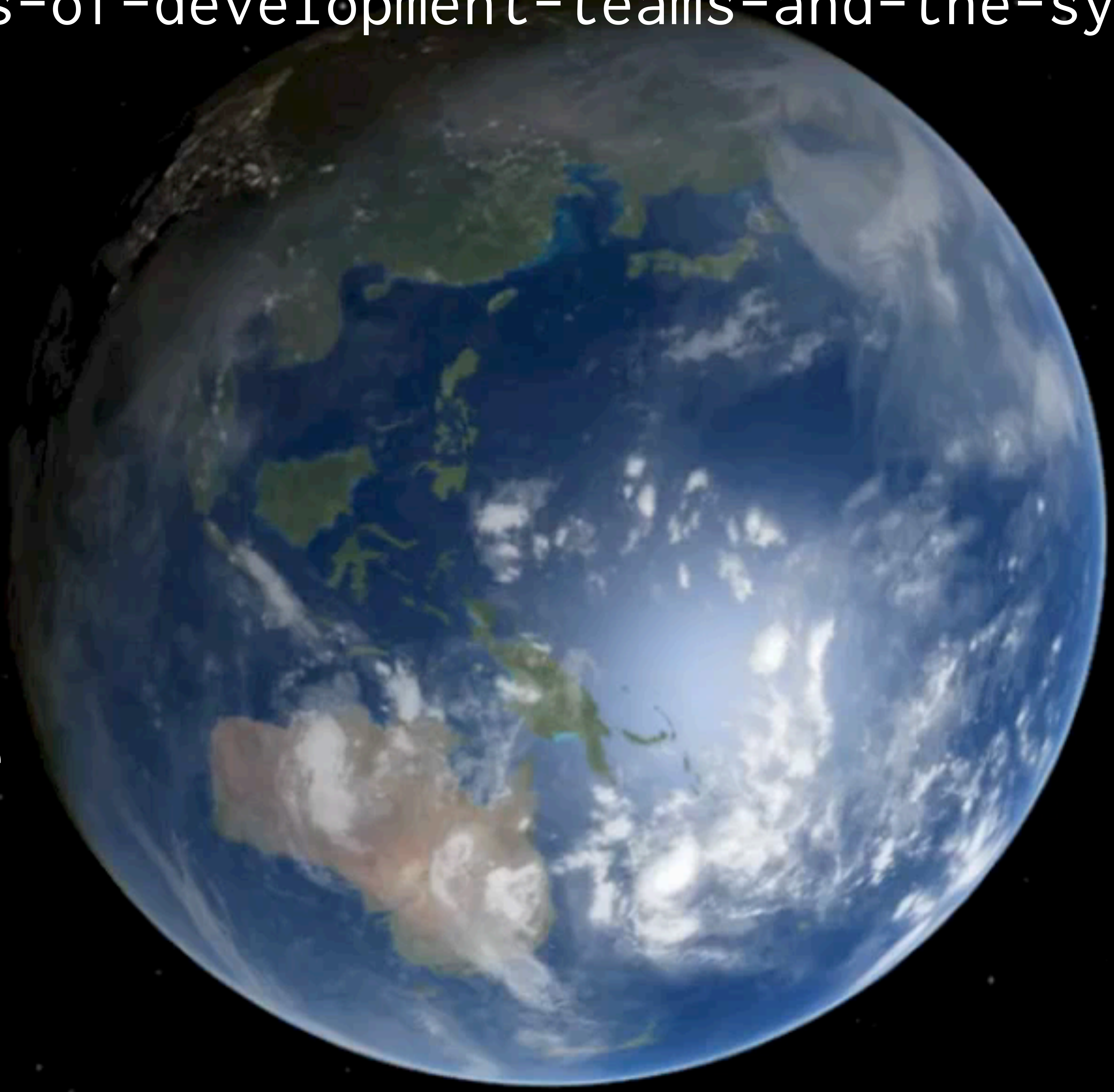
Software Process Dynamics

Sure it's fun! But is it useful?

Software Process Dynamics

- Secure **buy-in** for modelling and models
- **Parameterise** the model
- As **simple** as possible, but no simpler
- Be clear on system boundary / **assumptions**
- **Experiment!**
- **Discuss** results

http://sixty-north.com/blog/predictive-models-of-development-teams-and-the-systems-they-build



Thank you!

Robert Smallshire

@robsmallshire

SixtyNORTH

@sixty_north

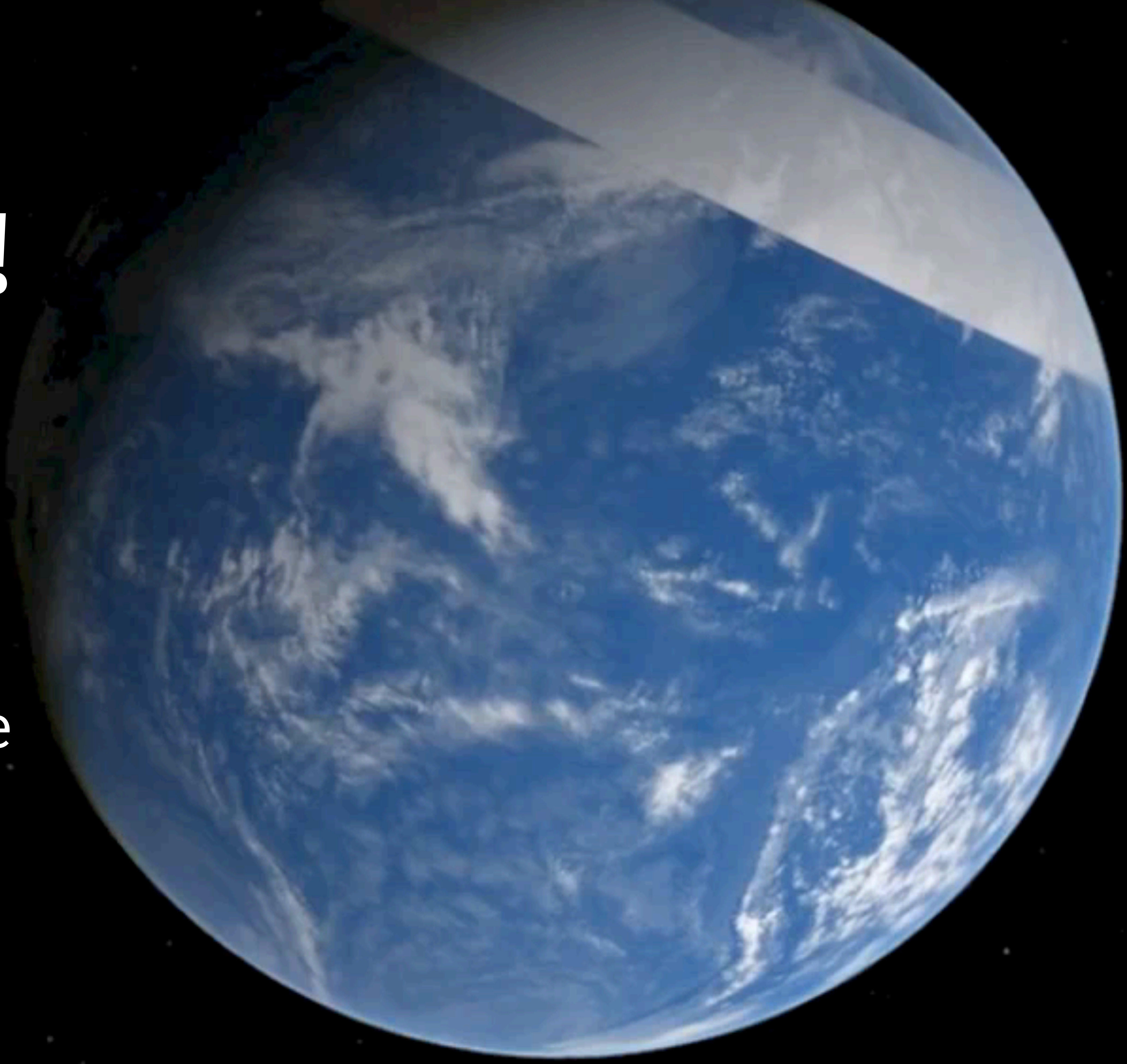
http://sixty-north.com/blog/predictive-models-of-development-teams-and-the-systems-they-build

Thank you!

Robert Smallshire

@robsmallshire

http://sixty-north.com/blog/predictive-models-of-development-teams-and-the-systems-they-build



Thank you!

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@robsmallshire

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@sixty_north

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Thank you!

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@robsmallshire

SixtyNORTH