Analysis and Justification of a Simple, Practical 2 1/2-D Capacitance Extraction Methodology

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Trends for Deep Submicron Designs

- Higher interconnect density
  - layer number: 6 in 1997, 8 in 2000
  - wire width/spacing: 0.40um in 0.35 process
0.22um in 0.18 process
- Higher wire aspect ratio
  - thickness/width: 1.5 for 0.35 process
2.5 for 0.18 process
- Lower noise margin
  - due to: dynamic logic cell
reduced supply voltage
... ...

Capacitance Extraction

- Slow but clean method
  - 3-D method numerical magnetic field solver

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  - 1-D method — unit-length total cap
  - 2-D method — unit-area cap
    unit-length lateral+fringe cap

Capacitance Extraction

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    unit-length lateral+fringe cap
- Fast and clean methods
  - 2 1/2-D method
    2-D method + corrections for adjacent layers

Capacitance Extraction

- Fast and clean methods
  - 2 1/2-D method
    2-D method + corrections for adjacent layers
  - possible analytical model ... ...

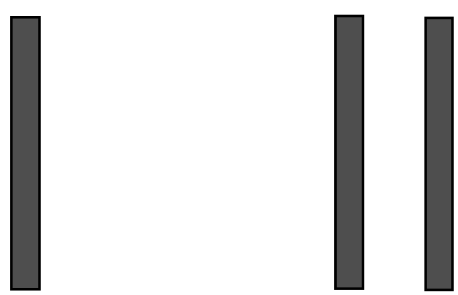
⇨ Easy to support during deep-submicron layout design

Overview

- ☑ Five foundations to validate the 2 1/2-D method
    - Verification method
    - Foundations
- ☐ A simple, practical 2 1/2-D method

Key to Foundation Verification

- Minimum metal density requirement
  - Set by foundry for planarization consideration
  - At least 30% in terms of area occupancy
  - May in form of dummy metals



Key to Foundation Verification

- Minimum metal density requirement
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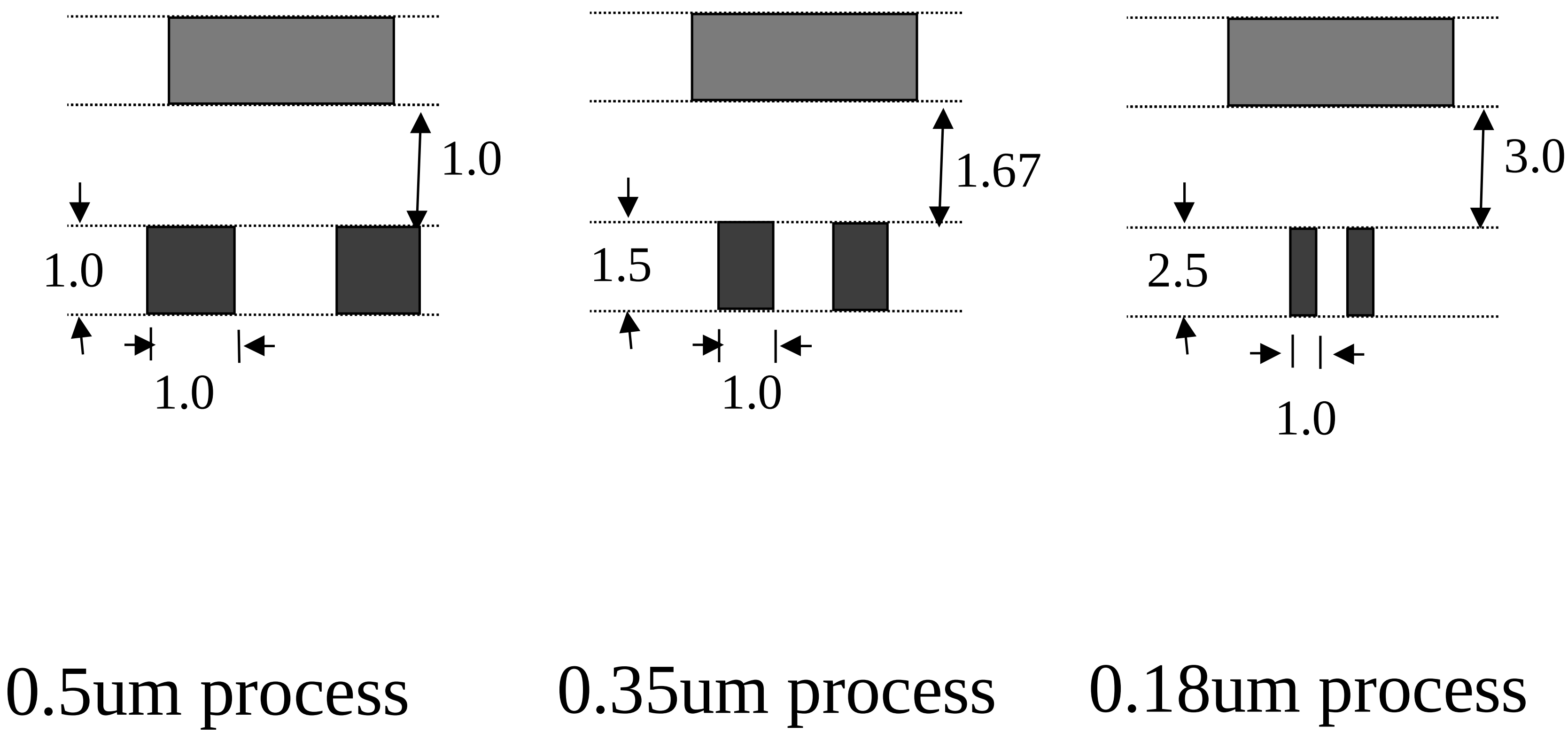
3-D Method for Foundation Verfication

- 3-D method (FastCap) is used to verify each foundation
  - Assume wires are orthogonal on adjacent layers
  - Solve maximum-density interconnect structures
  - Measure the lumped capacitance for victim
  - Use geometric parameters in SIA RoadMap (for 0.5, 0.35 and 0.18 processes)

Normalized Geometric Parameters



Foundation I

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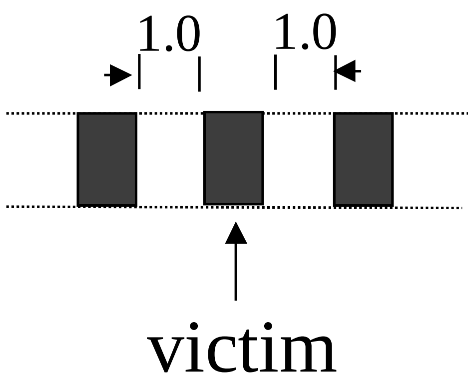
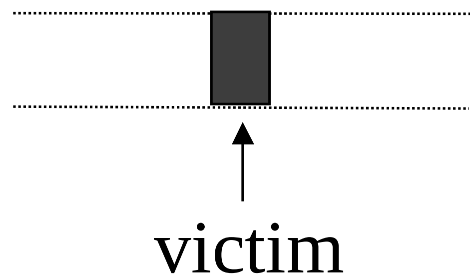
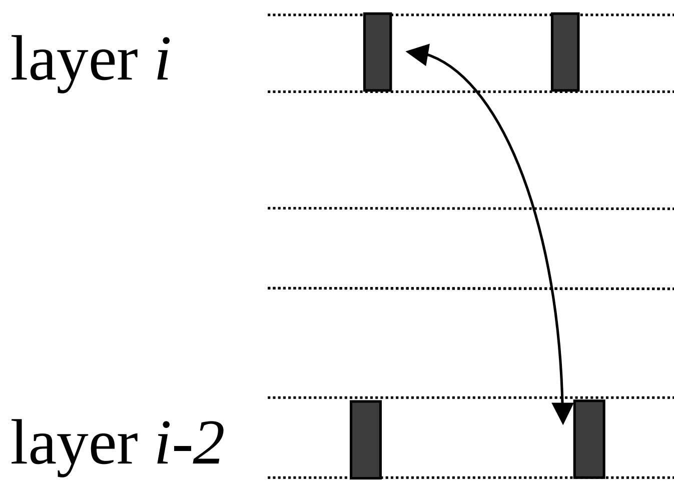
Effect of Neighbors





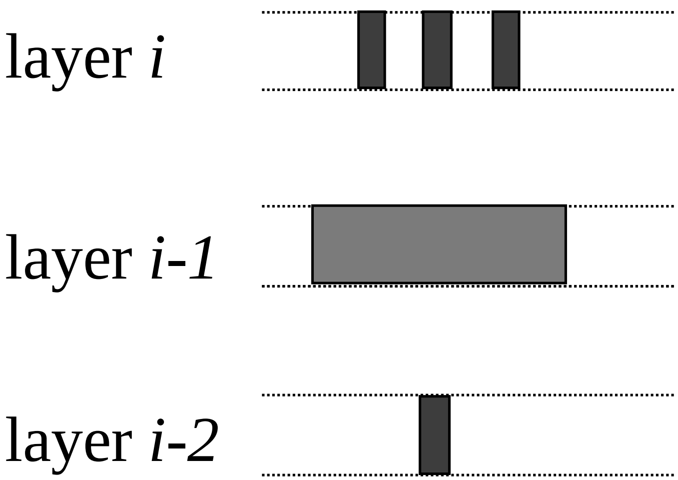
Two extreme cases are solved in experiments.

Coupling between Layers *i* and *i-2*



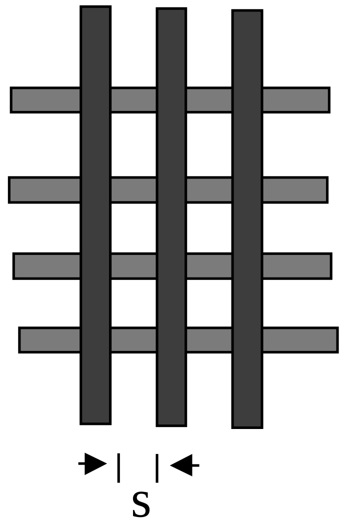
Given tall and long parallel sidewalls,
how worse may it be?

Coupling between Layers *i* and *i-2*



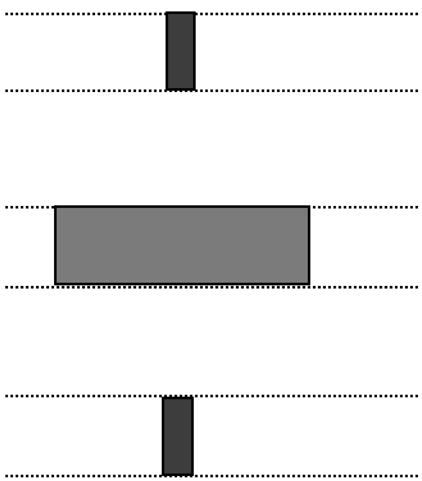
cross-section

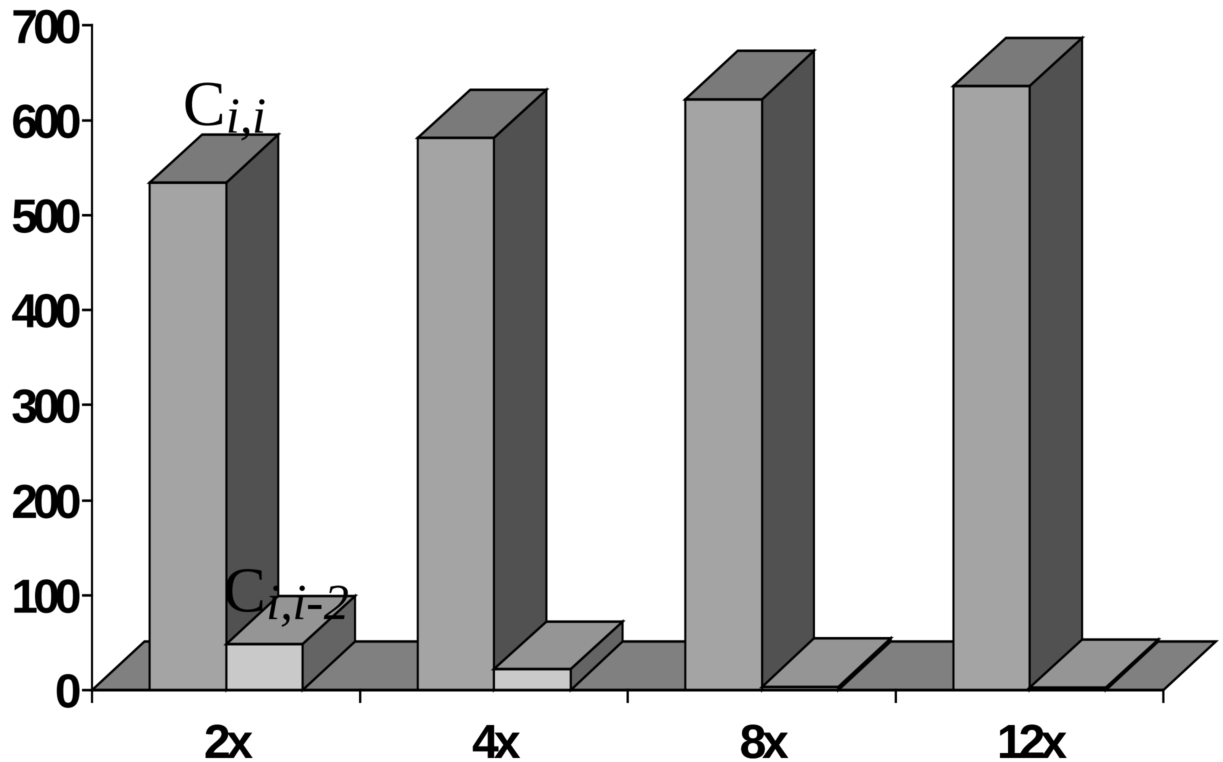
crossunders
(4x)



top-view

Coupling between Layers *i* and *i-2*

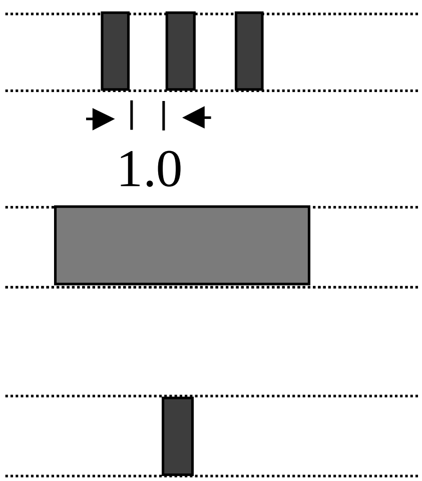


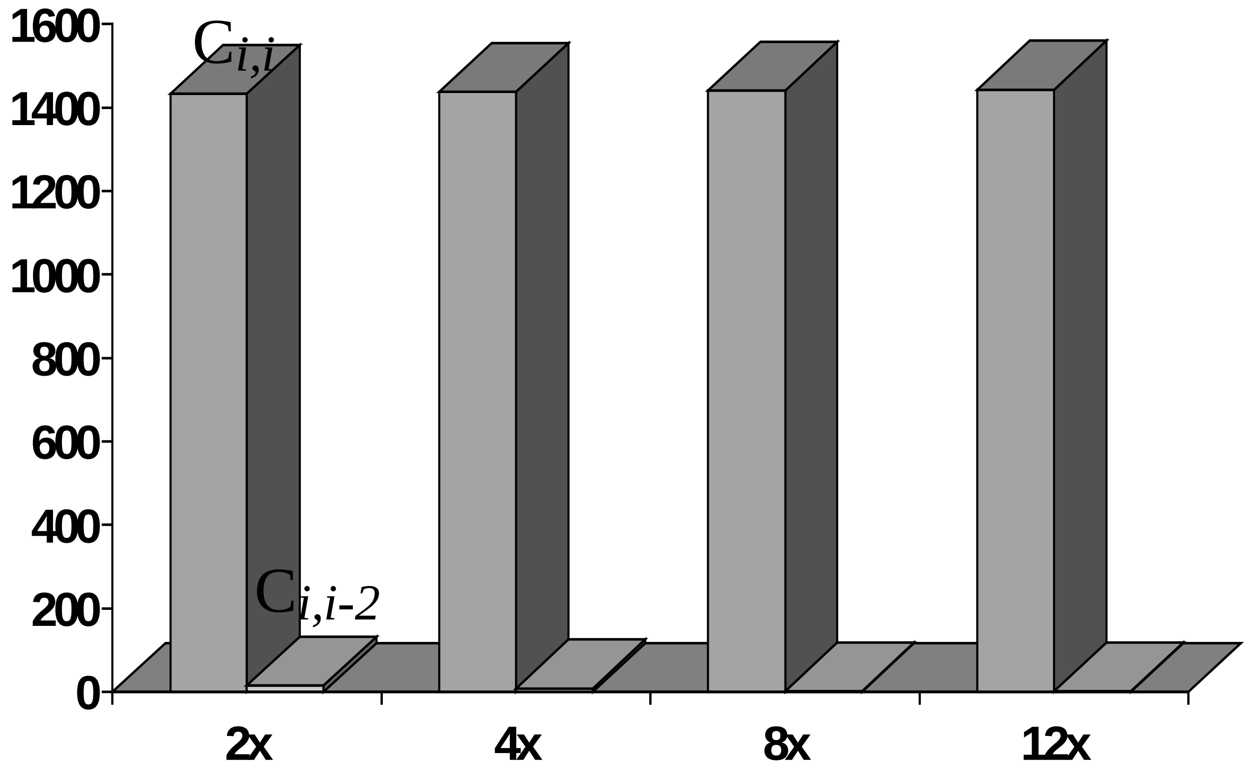


$C_{i,i}$ total capacitance for victim on layer *i*

$C_{i,i-2}$ coupling between victim and wire on layer *i-2*

Coupling between Layers *i* and *i-2*





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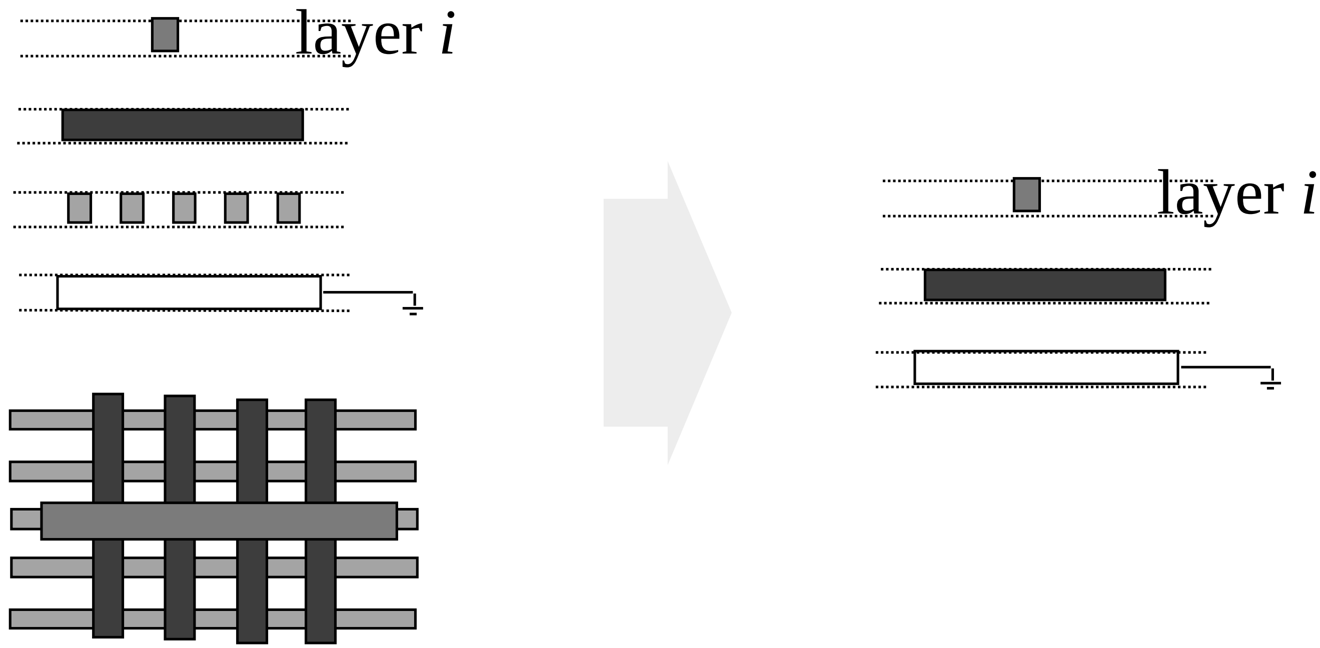
Foundation II

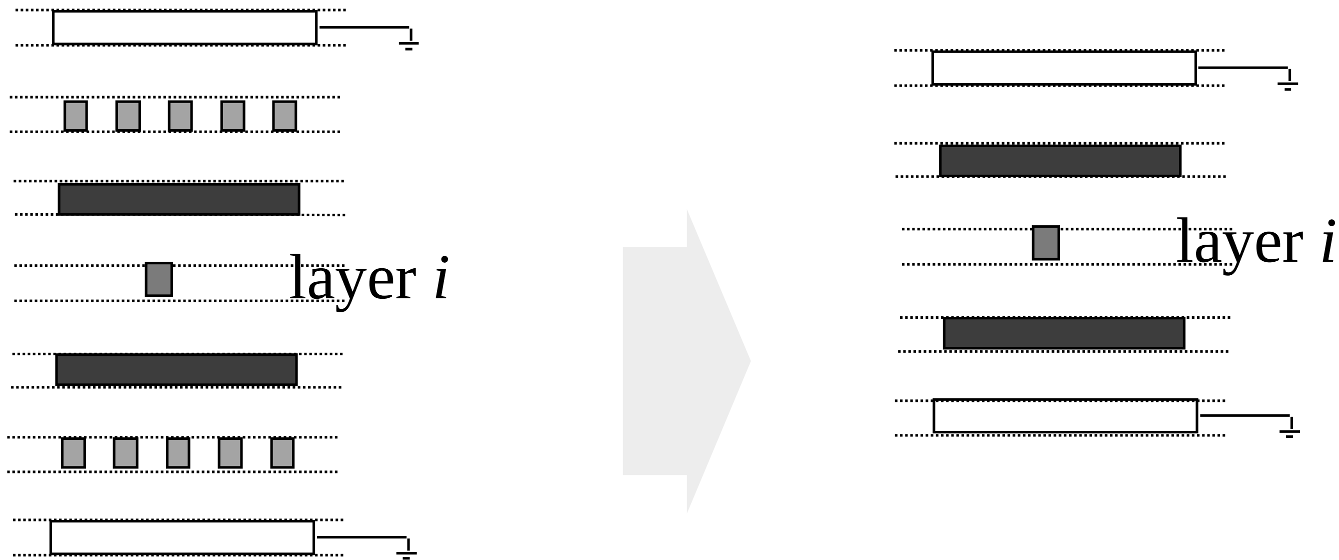
[redacted]

Coupling Effect of Layers *i+2* and *i-2*



Errors are within 0.5% for $C_{i,i}$ of victim.

Coupling Effect of Layers *i+2* and *i-2*

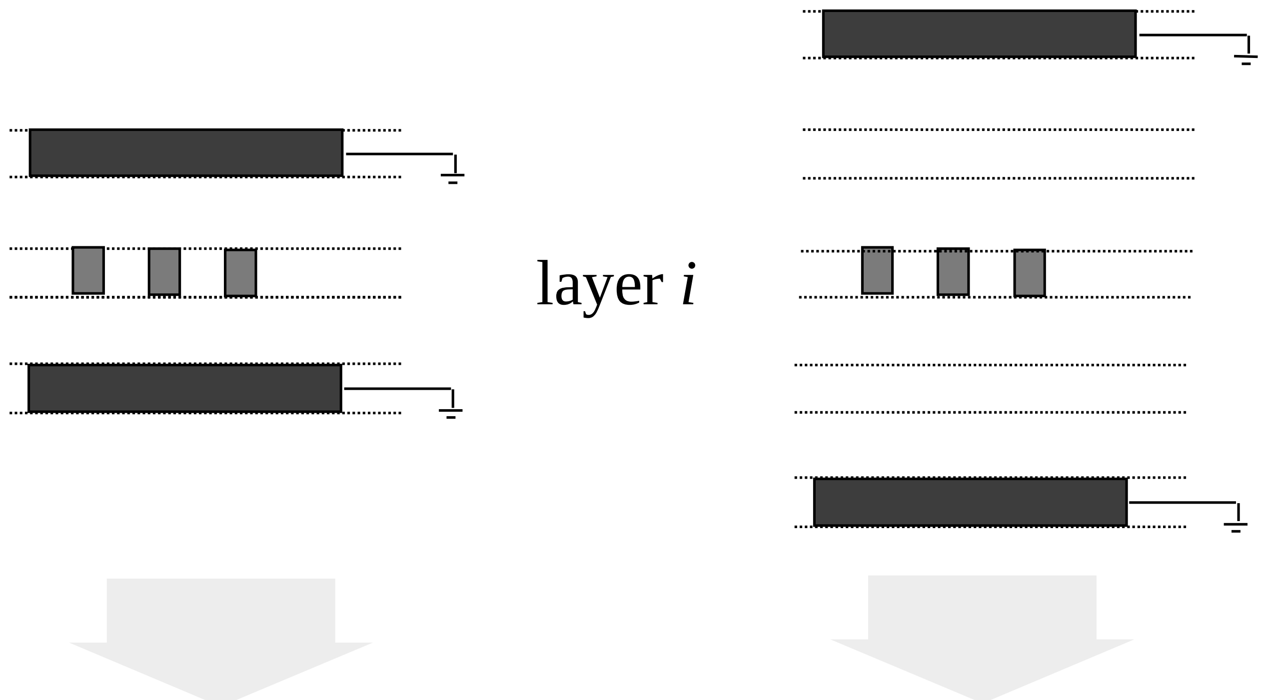


Errors are again within 0.5% for $C_{i,i}$ of Victim.

Foundation III

[redacted]

Coupling between Wires on Same Layer



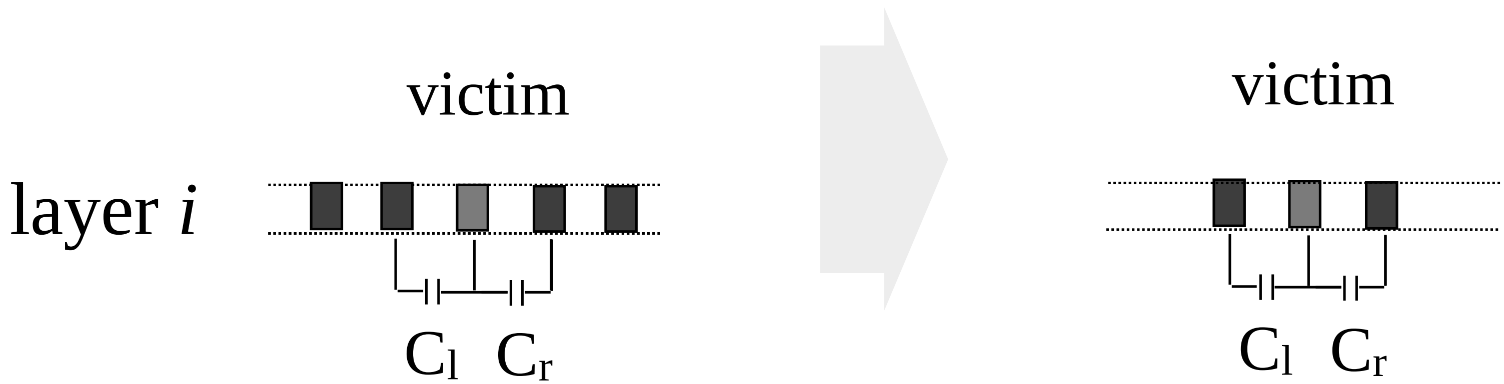
Optimistic pattern

derestimateuns couplings
between wires on layer *i*

Pessimistic pattern

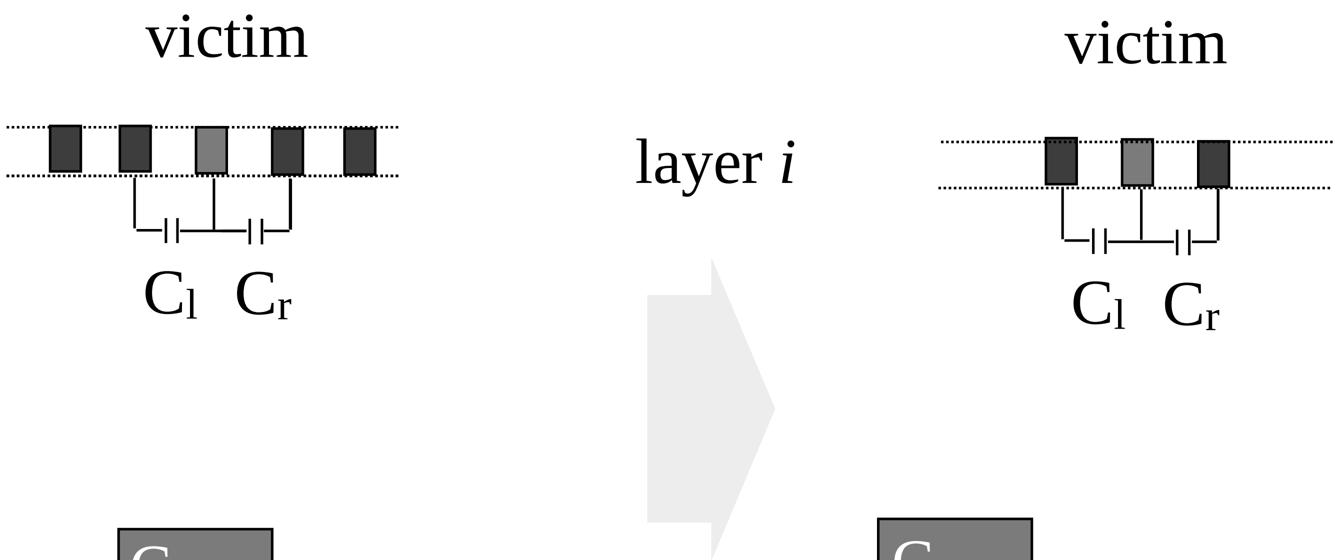
overstimates couplings
between wires on layer *i*

Coupling between Wires on Same Layer



Errors are within 0.3% for $C_{i,i}$, C_l and C_r.

Coupling between Wires on Same Layer

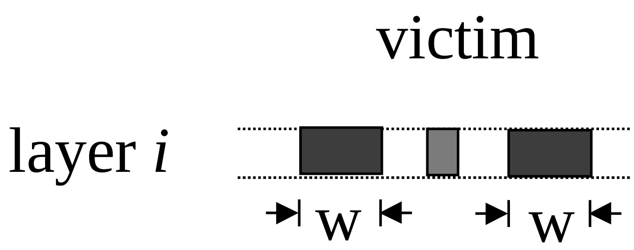


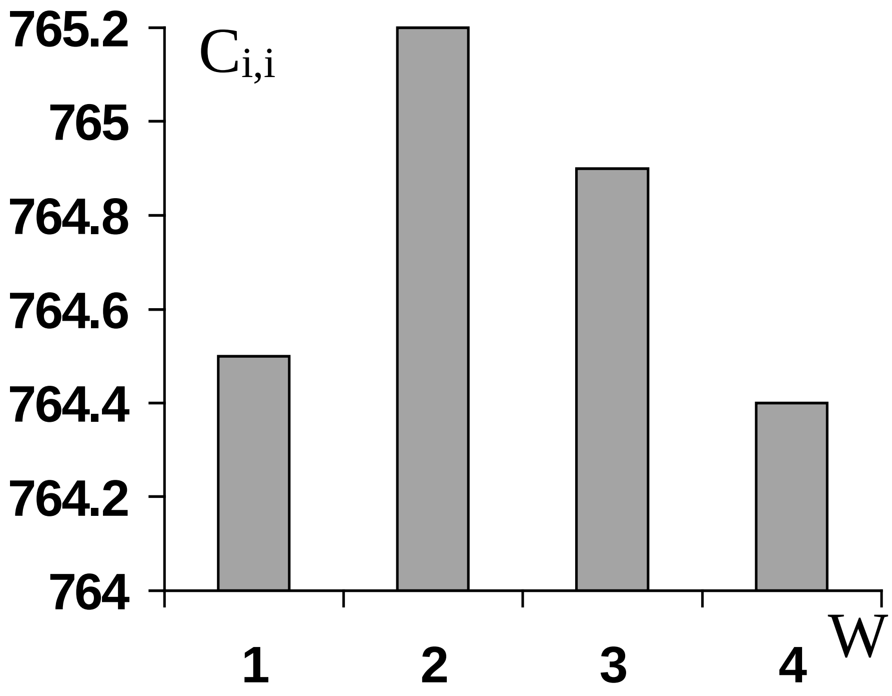
$C_{i,i}$
1451
1436

$C_{i,i}$
1451
1436

Only nearest neighbors are needed to be considered.

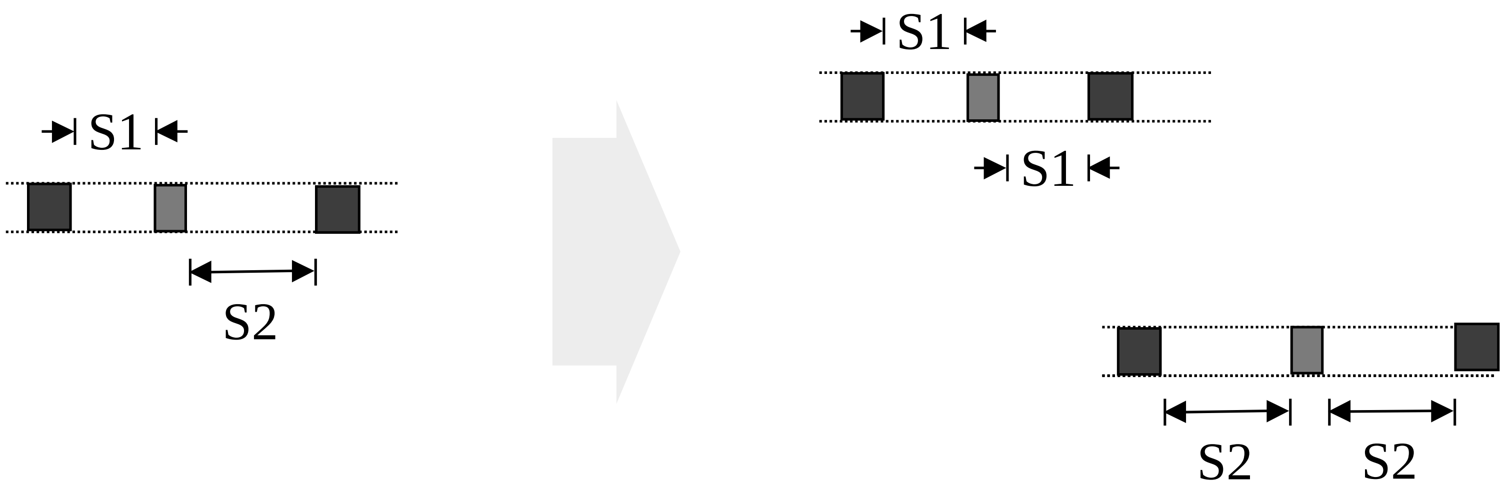
Coupling between Wires on Same Layer





$C_{i,i}$ varies less that 0.3% for different neighbor widths.

Coupling between Wires on Same Layer



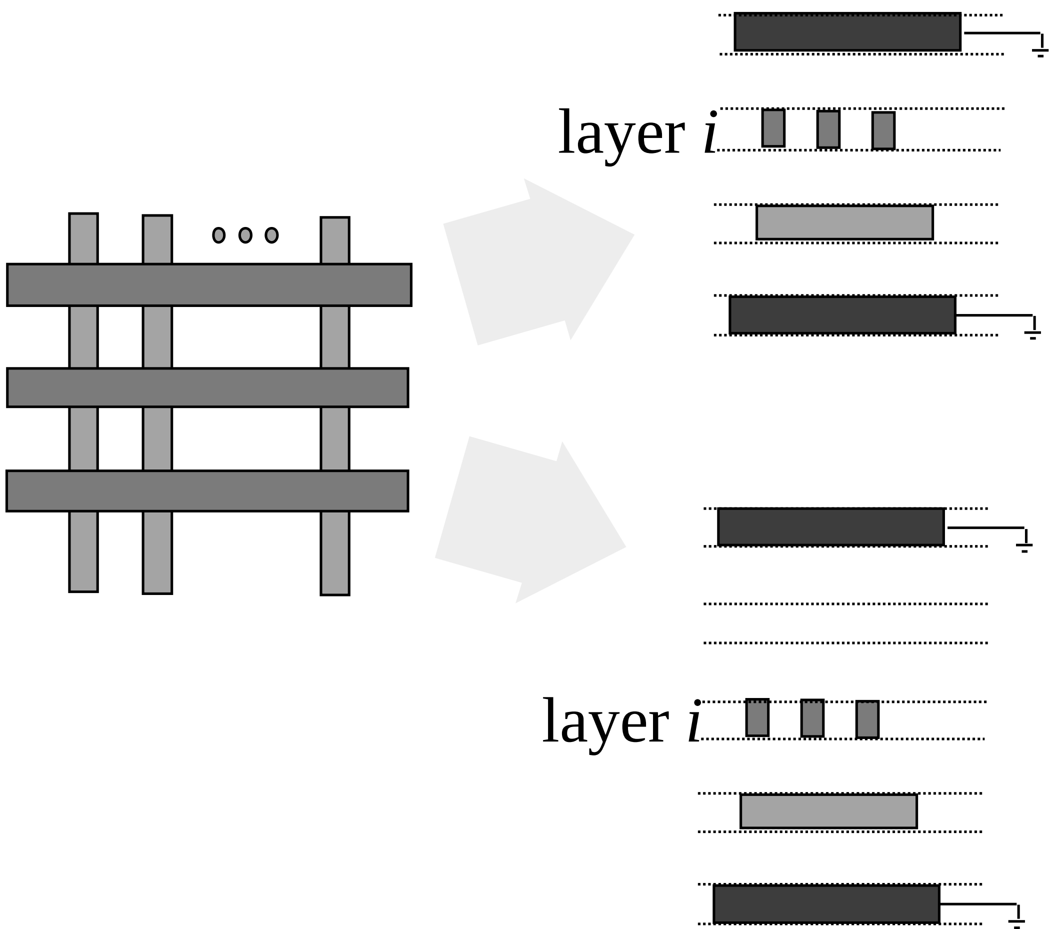
$$C_{i,i}(S1,S2) \Leftrightarrow \frac{C_{i,i}(S1,S1) + C_{i,i}(S2,S2)}{2}$$

i.e., the interaction between neighbors is negligible.

Foundation IV

[redacted]

Interaction between Crossovers and Crossunders



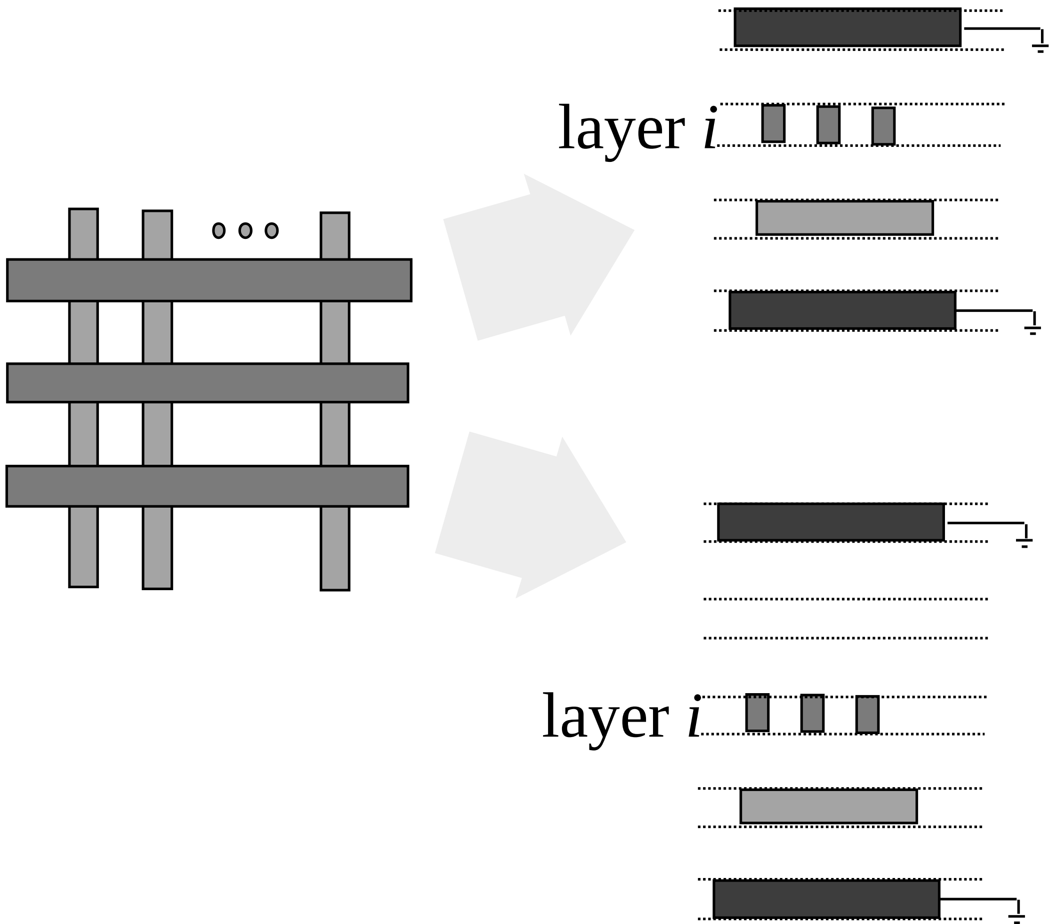
Pessimistic pattern

overstimates interaction for crossunders

Optimistic pattern

derestimates interaction for crossunders

Interaction between Crossovers and Crossunders



Pessimistic pattern

overstimates interaction for crossunders

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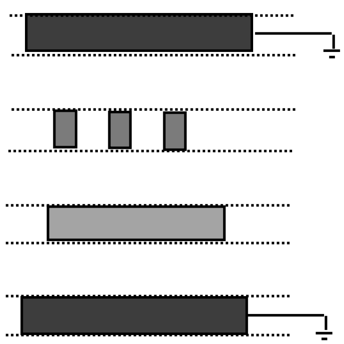
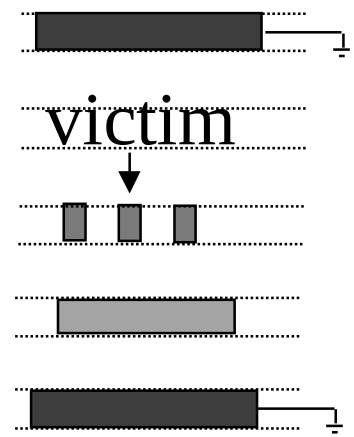
Interaction between Crossovers and Crossunders

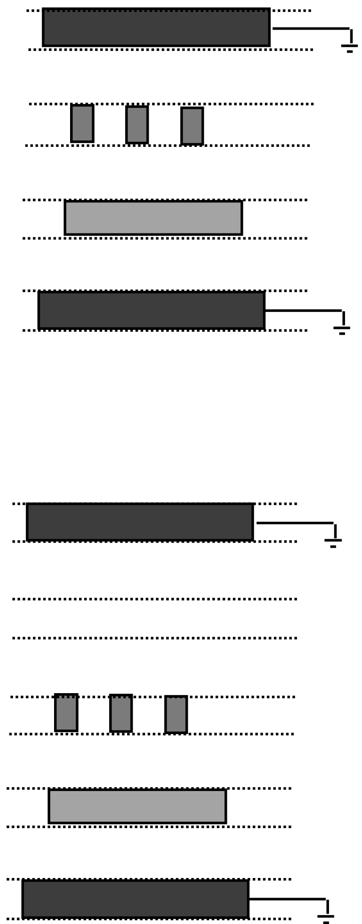


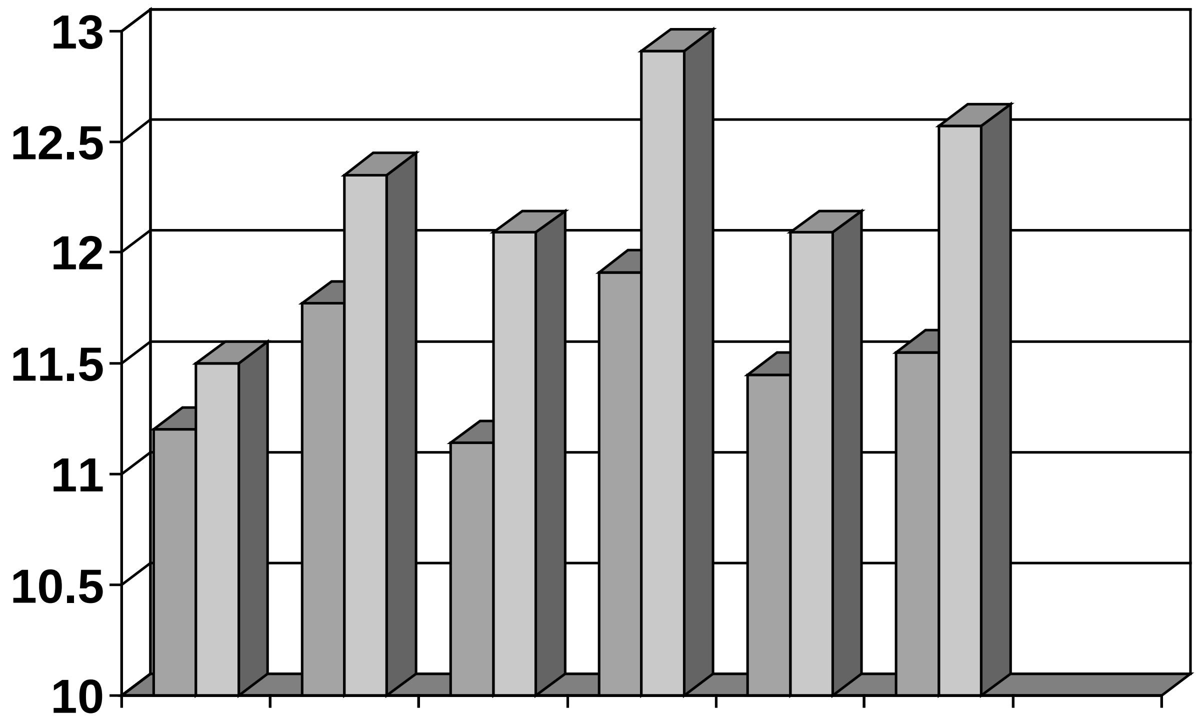


Couplings between victim and rossunders may differ up to 6%

2% variation for $C_{i,i}$

Interaction between Crossovers and Crossunders





Couplings between layer *i*
and crossunders for two patterns

Foundation V

[redacted]

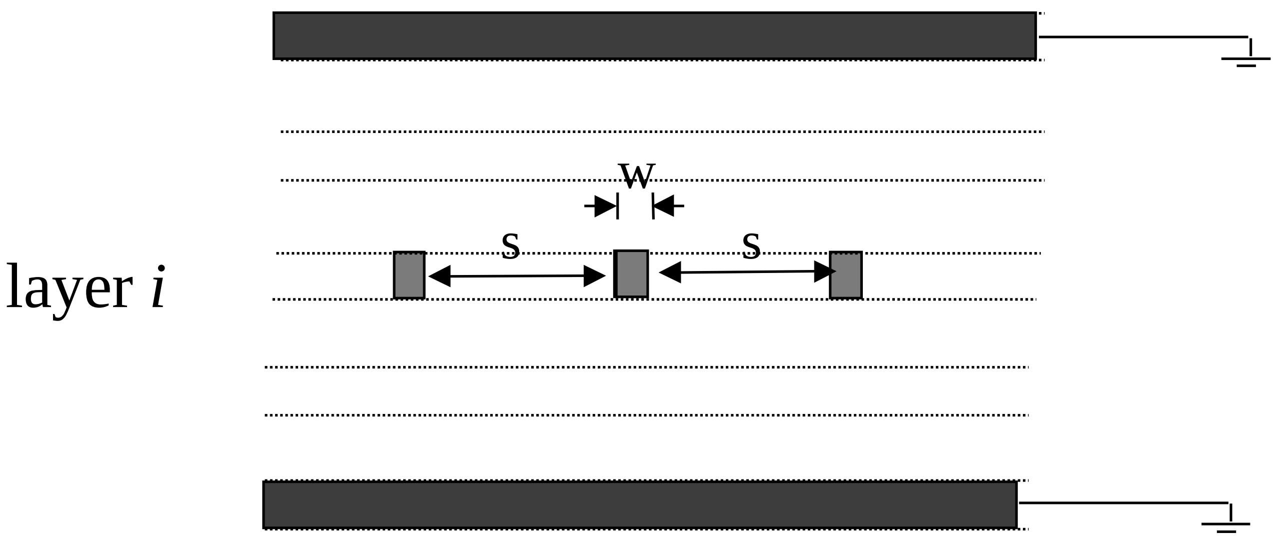
Overview

☐Foundations for 2 1/2-D method

☑A simple, practical 2 1/2-D method

- Table (cap coefficients) generation
  - One-time use of 3-D method
- 2 1/2-D algorithm
  - Possible use of inter- and extra-polation

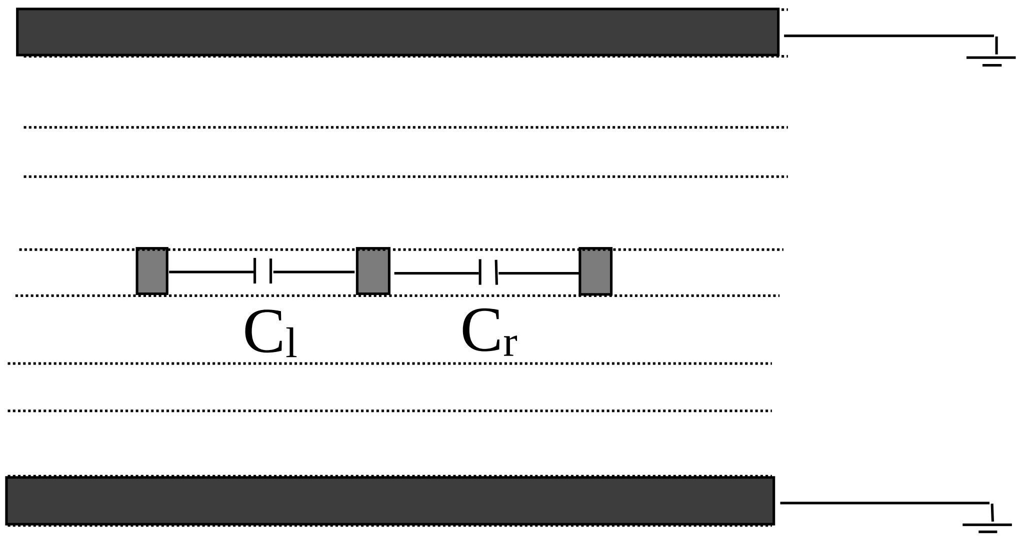
Lateral, Area and Fringe Capacitances



Capacitances are computed for each (w,s)

Lateral Capacitance Coefficient

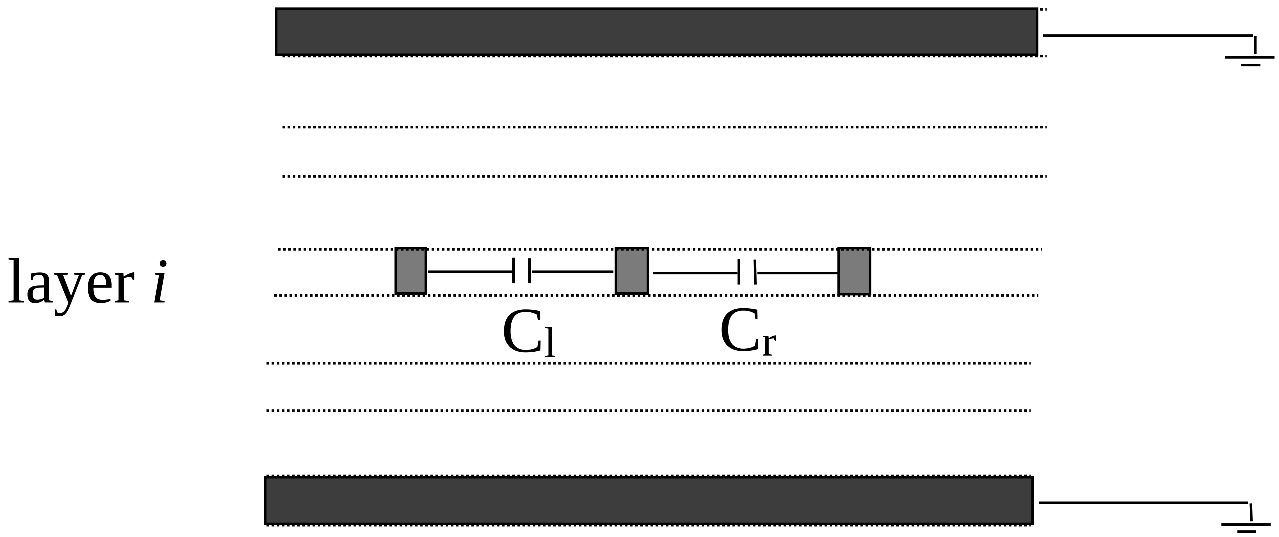
layer *i*



Per-side and unit-length lateral capacitance is

$$C_L(w,s) = \frac{C_l + C_r}{2*L}$$

Area and Fringe Capacitance Coefficients

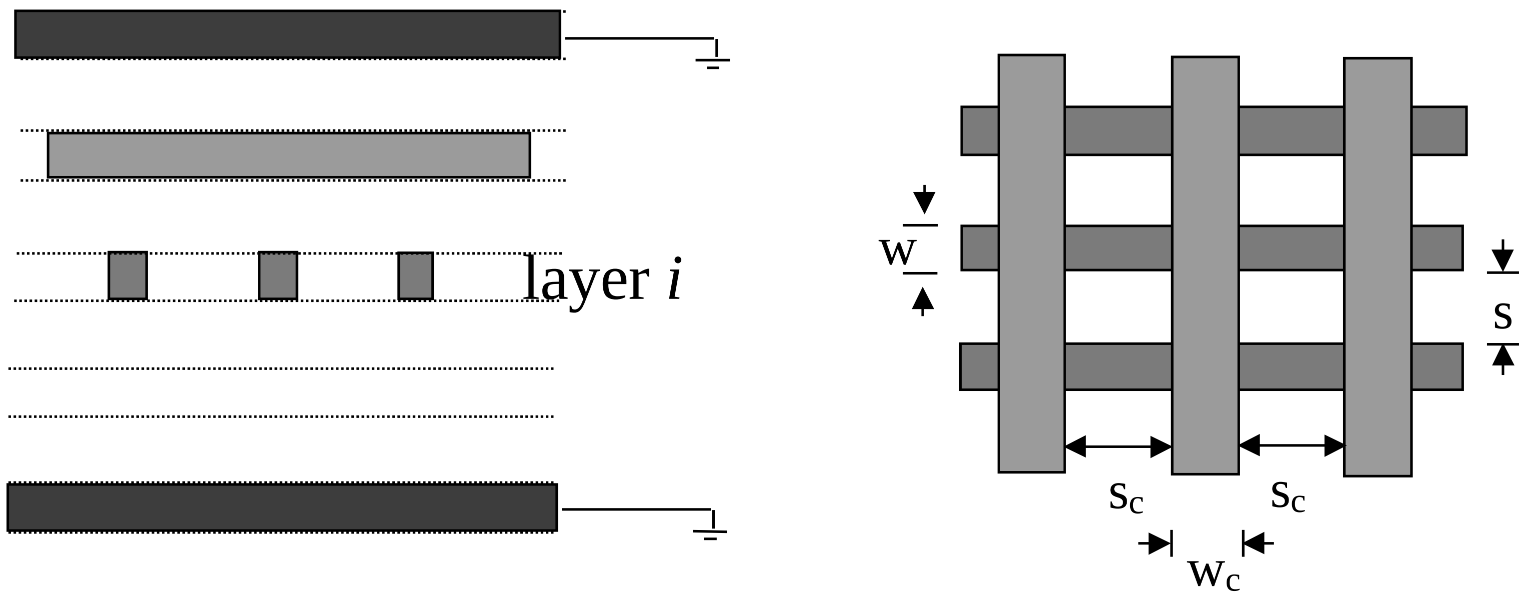


The coupling excluding C_l and C_r is separated into

$C_A(w,s)$ per-side, unit-length area capacitance

$C_F(w,s)$ per-side, unit-length fringe capacitance

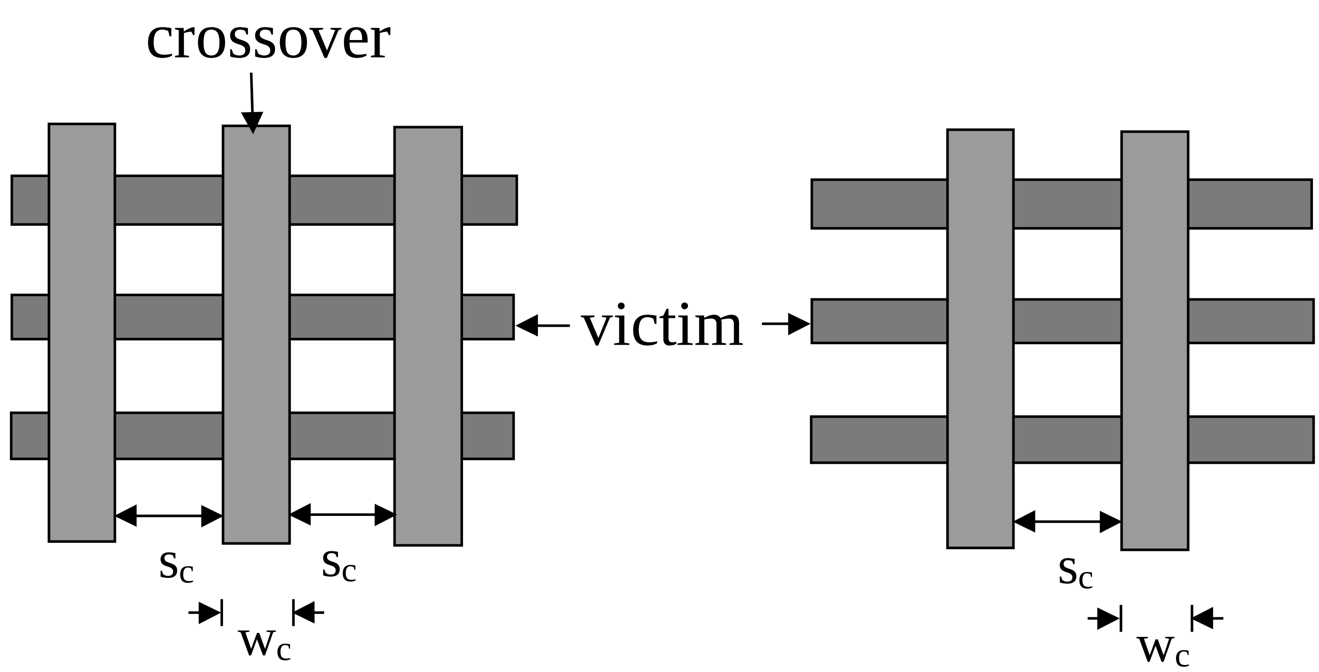
Cross Wire Correction Capacitances



Crossover and crossunder are independent and symmetric.

Each correction is computed for every (w,s,w_c,s_c)

Cross Wire Correction Capacitances



Per-corner correction capacitance is

$$C_{over}(w,s,w_c,s_c) = \frac{\Delta C_{i,i}}{4}$$

2 1/2-D Algorithm

For each victim

    For each side of the victim

        Count lateral, area and fringe capacitance w.r.t nearest neighbor

    EndFor

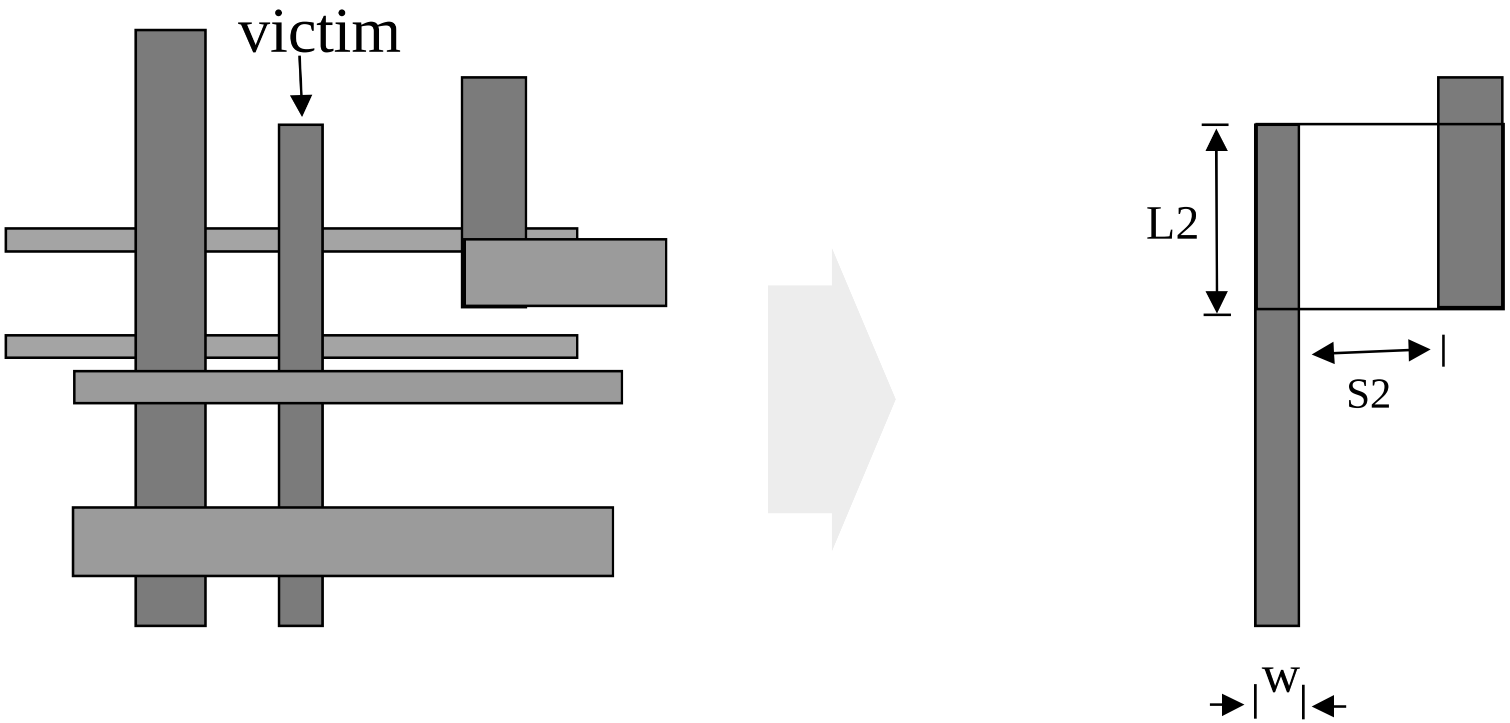
    For each crossover or crossunder of the vicitm

        Count correction corner by corner

    EndFor

EndFor each victim

2 1/2-D algorithm

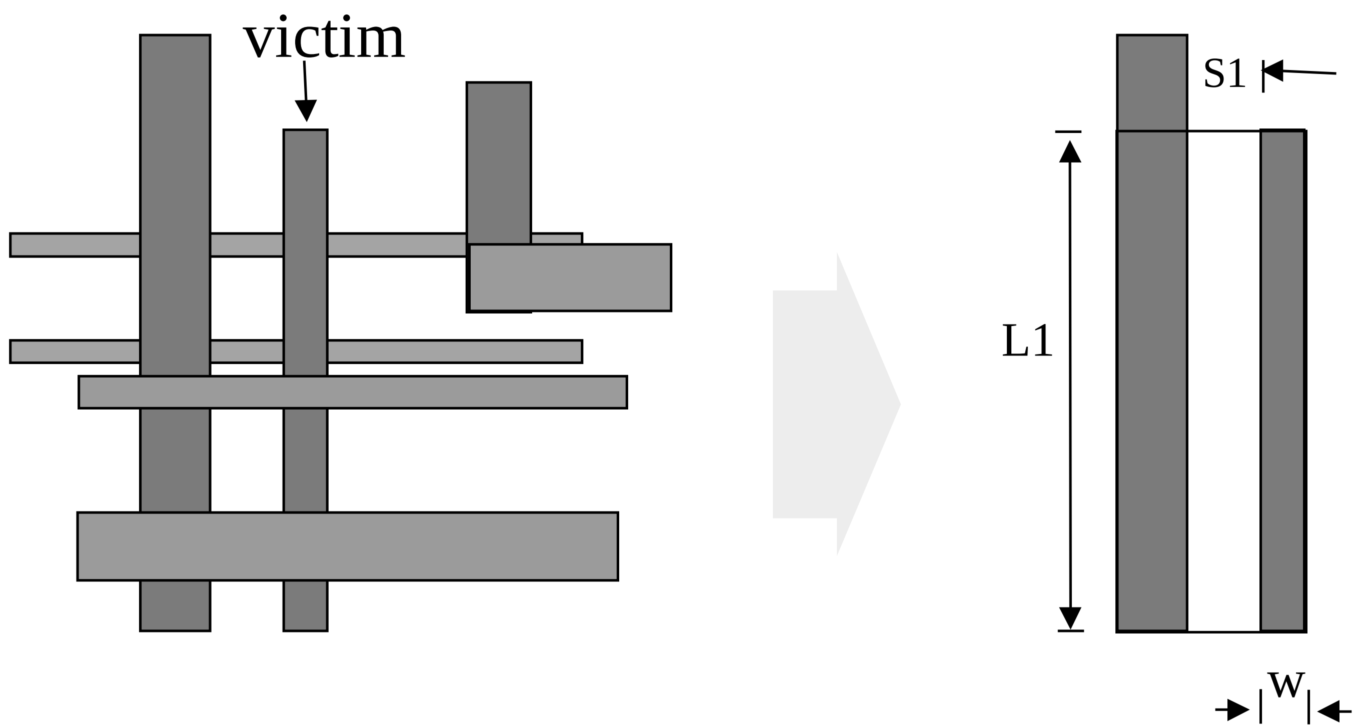


one-side lateral capacitance = $C_L(w,s_2) * L2$

one-side area capacitance = $C_A(w,s_2) * L2$

one-side fringe capacitance = $C_F(w,s_2) * L2$

2 1/2-D algorithm

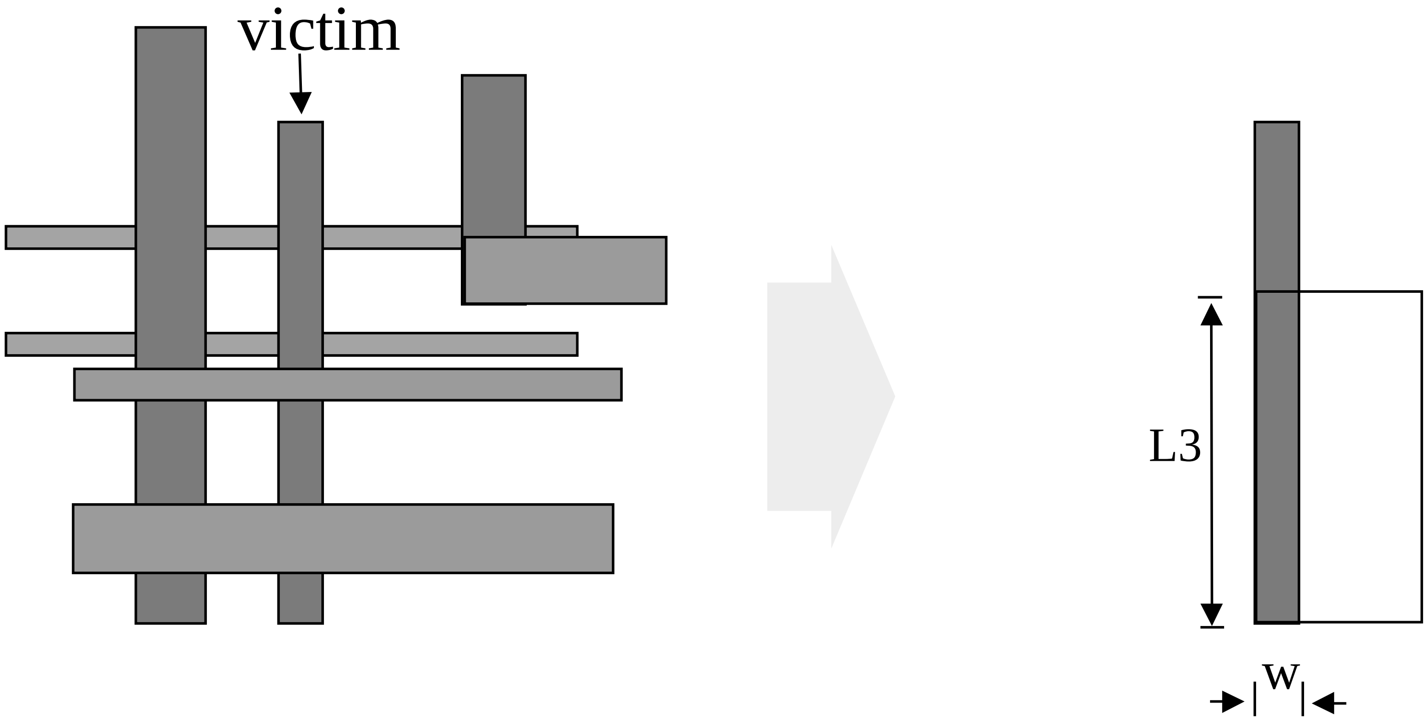


one-side lateral capacitance = $C_L(w,s_1) * L1$

one-side area capacitance = $C_A(w,s_1) * L1$

one-side fringe capacitance = $C_F(w,s_1) * L1$

2 1/2-D algorithm

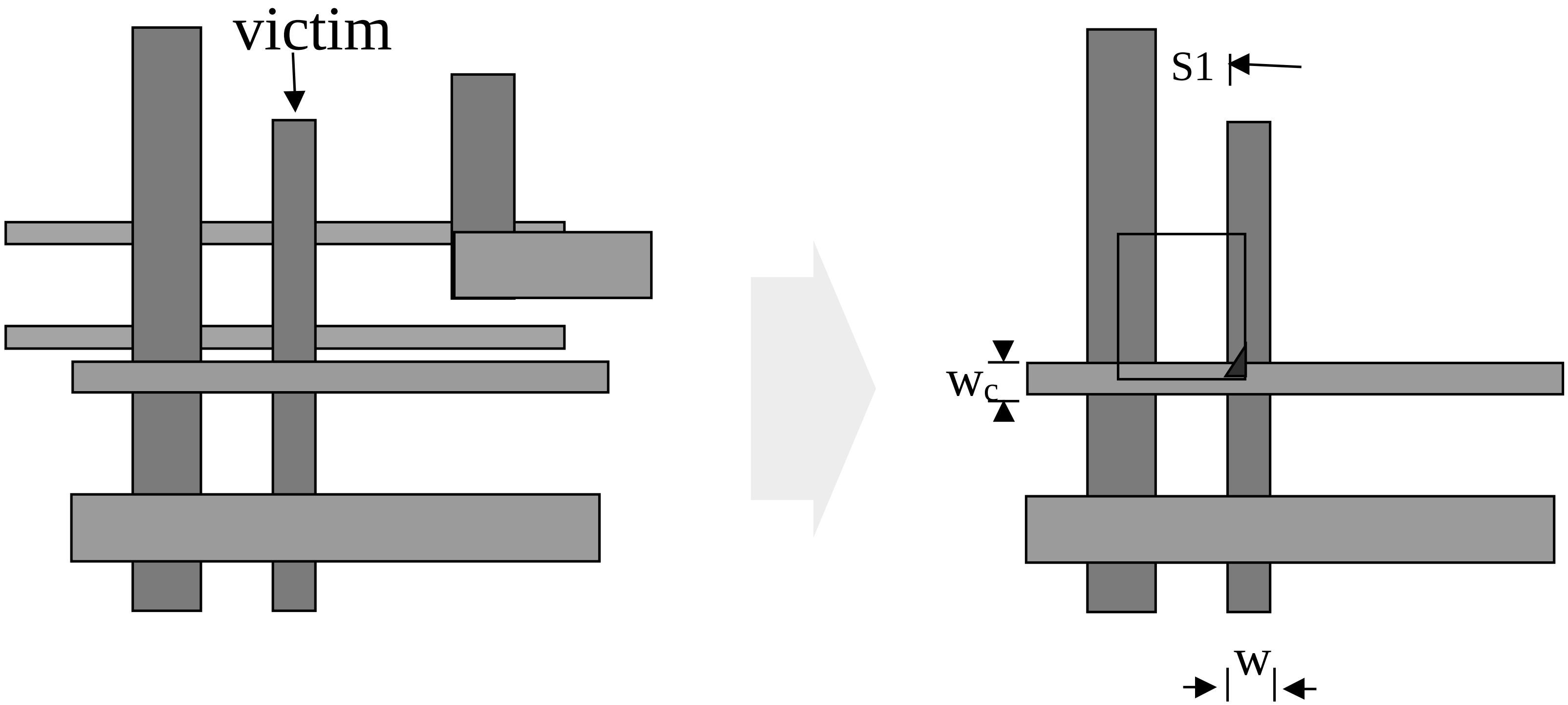


one-side lateral capacitance = $C_L(w,+) * L3$

one-side area capacitance = $C_A(w,+) * L3$

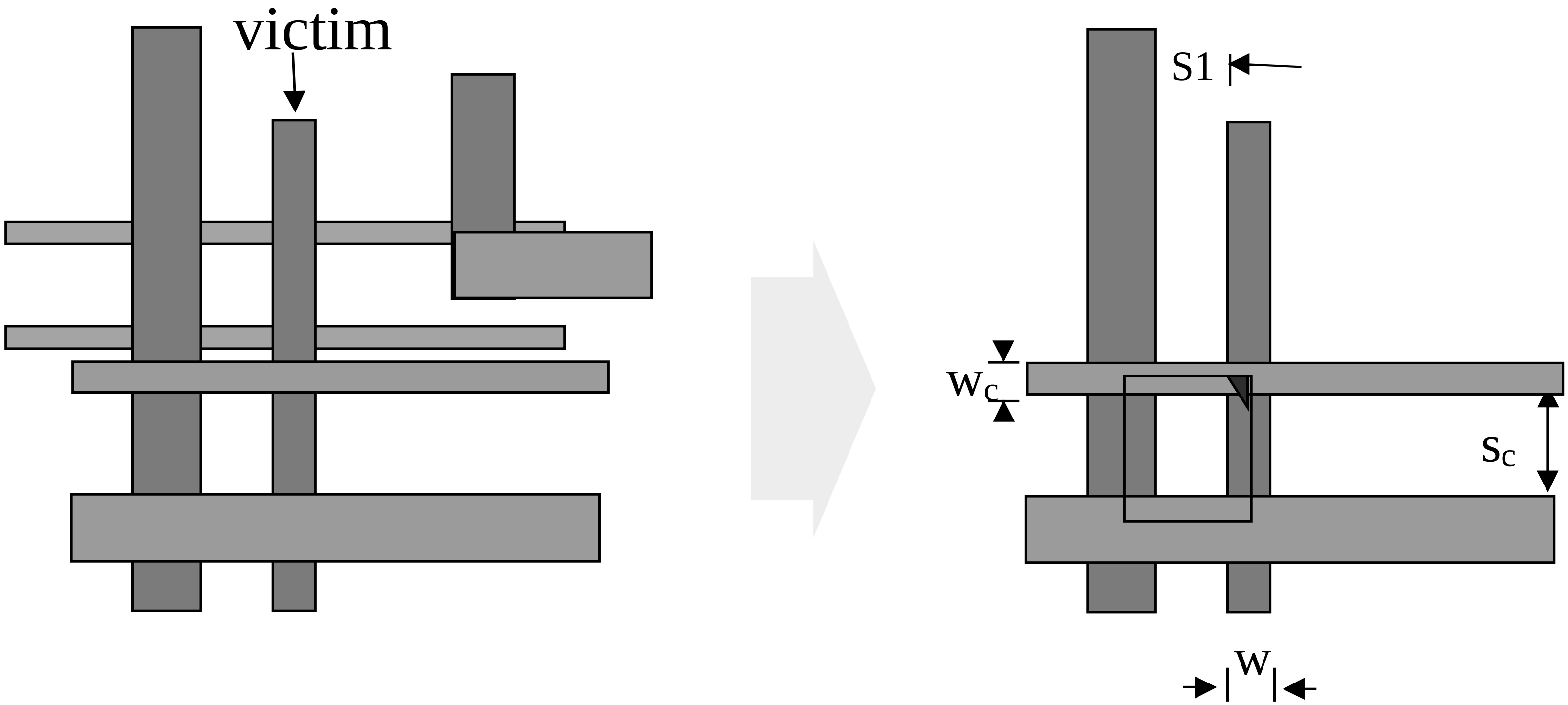
one-side fringe capacitance = $C_F(w,+) * L3$

2 1/2-D algorithm



One-corner crossover correction = $C_{over}(w, S1, w_c, +)$

2 1/2-D algorithm



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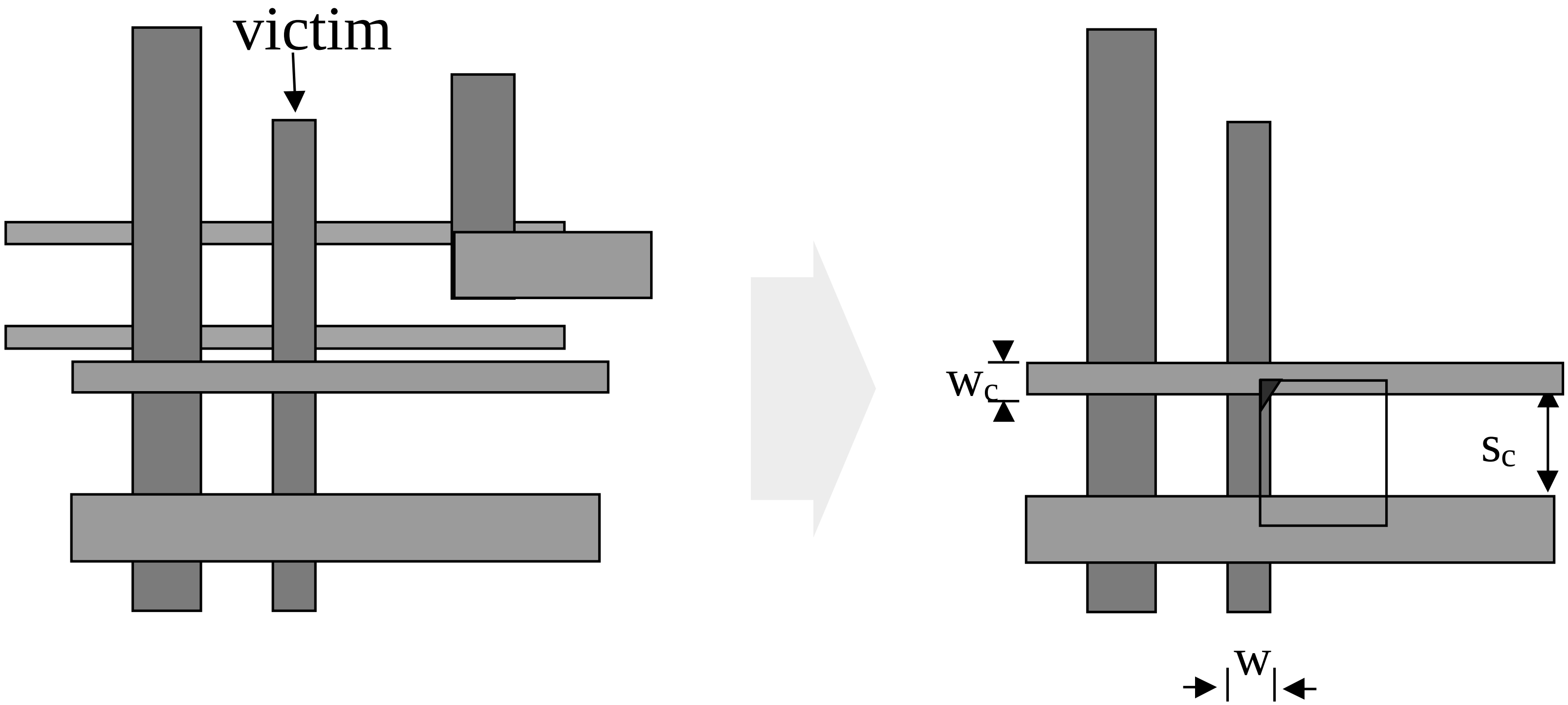
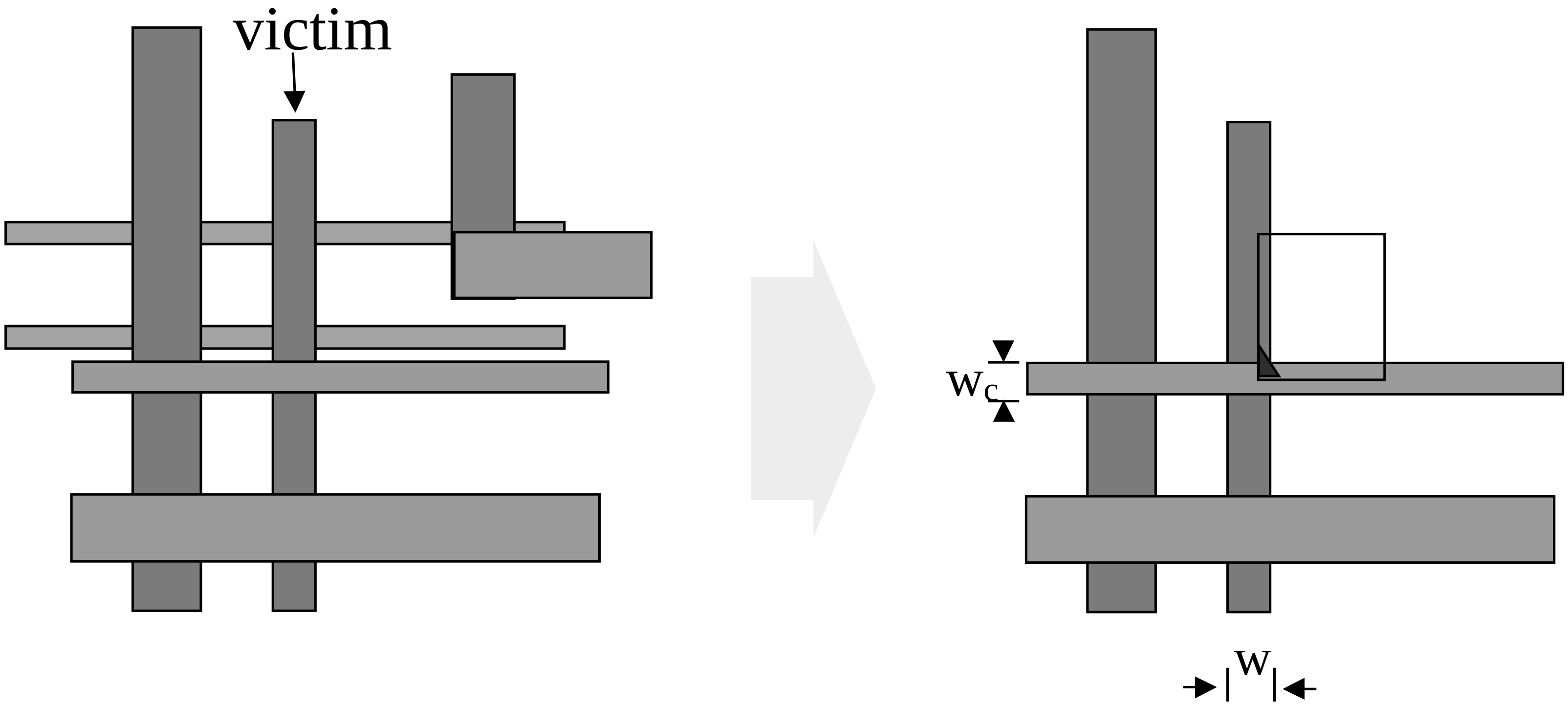
2 1/2-D algorithm



One-corner crossover correction = $C_{over}(w,+,w_c,s_c)$

2 1/2-D algorithm



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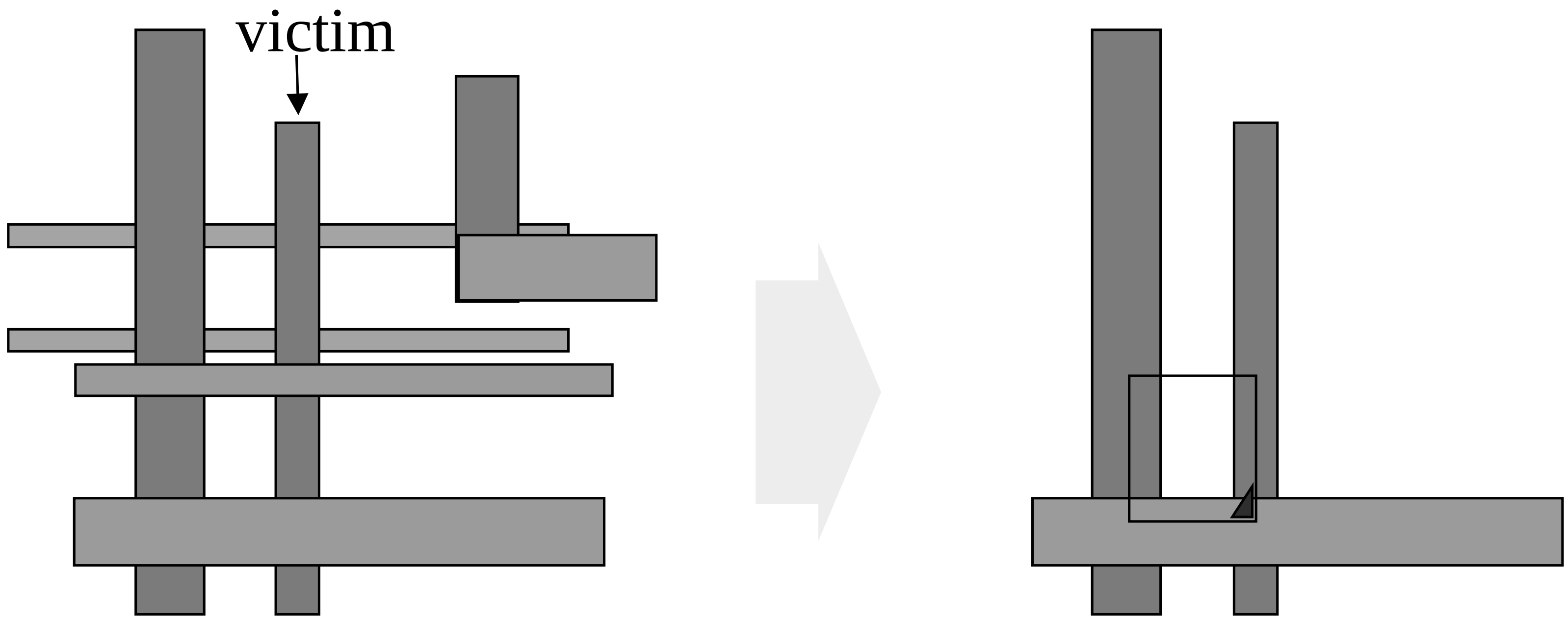
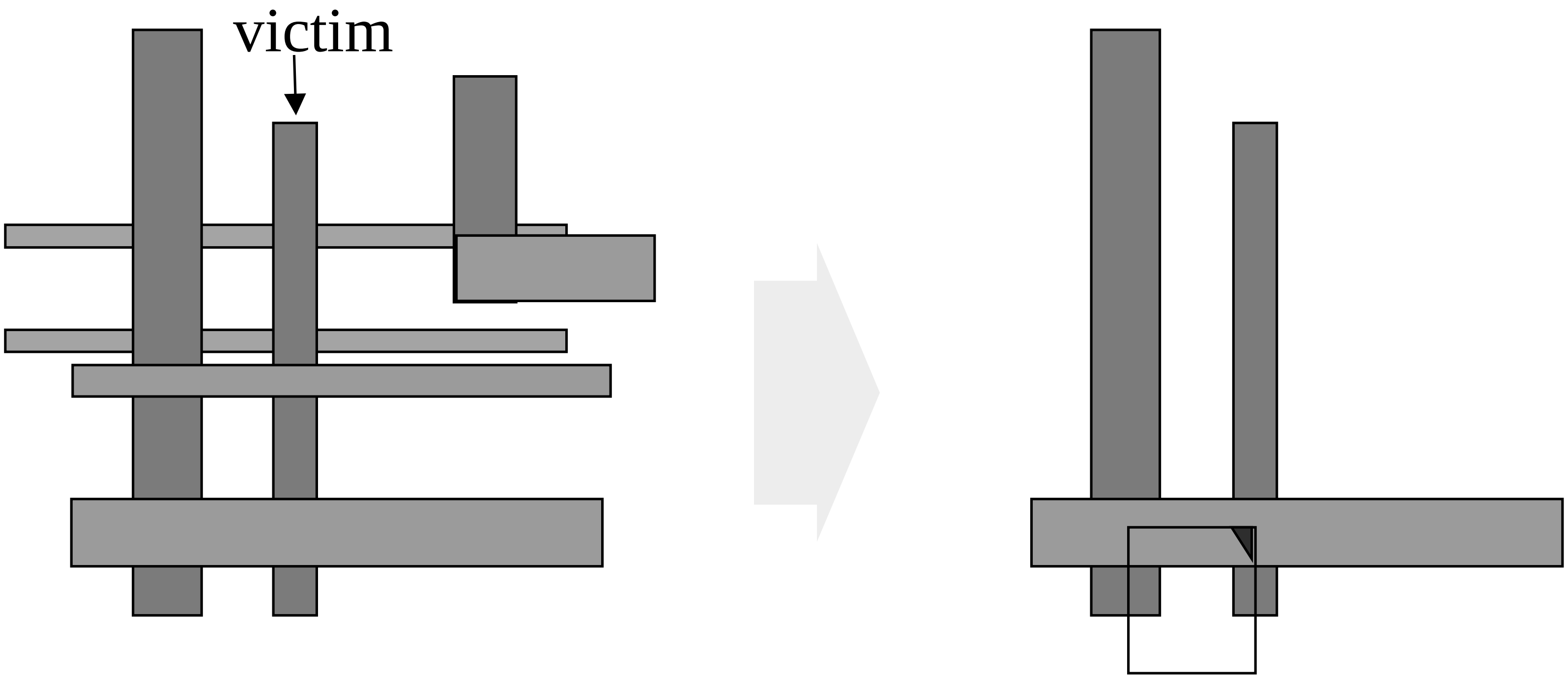
2 1/2-D algorithm



Count each crossover and crossunder.

2 1/2-D algorithm



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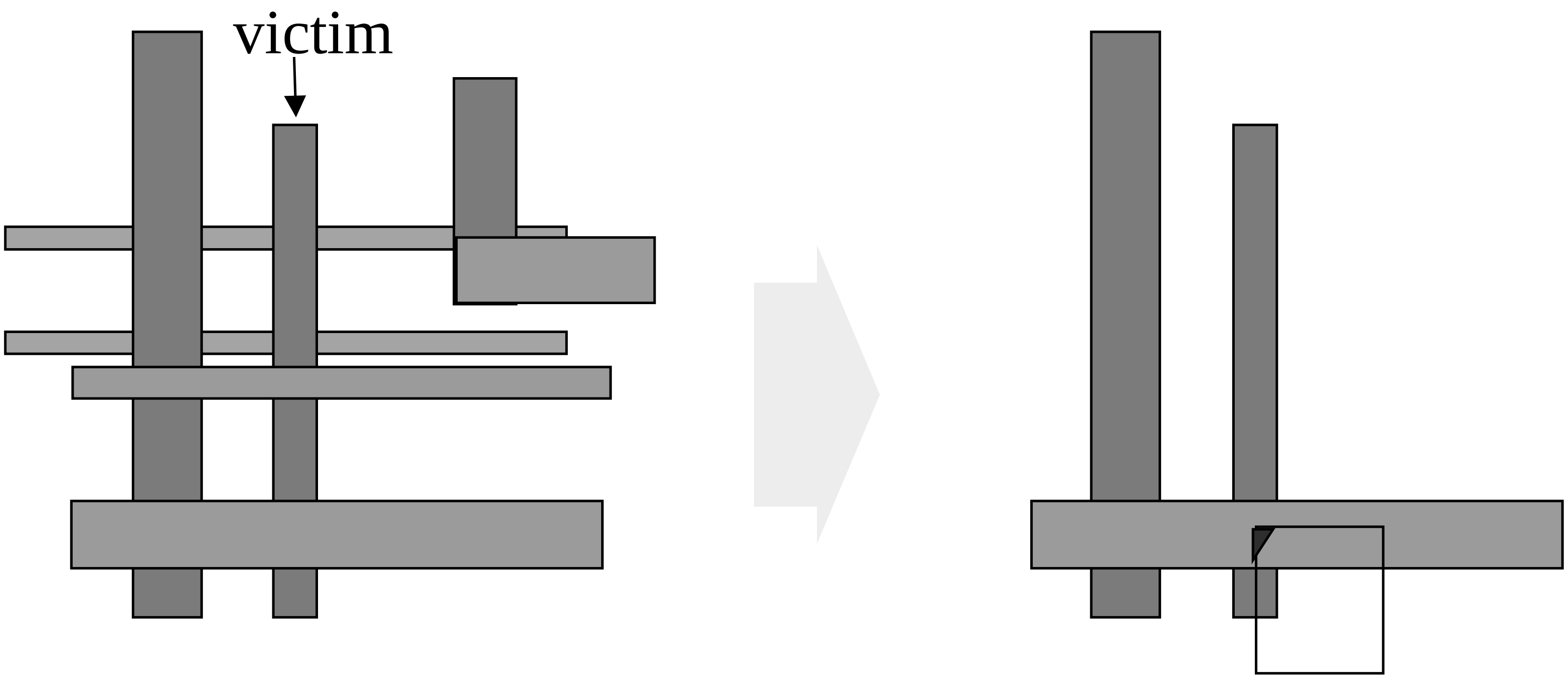

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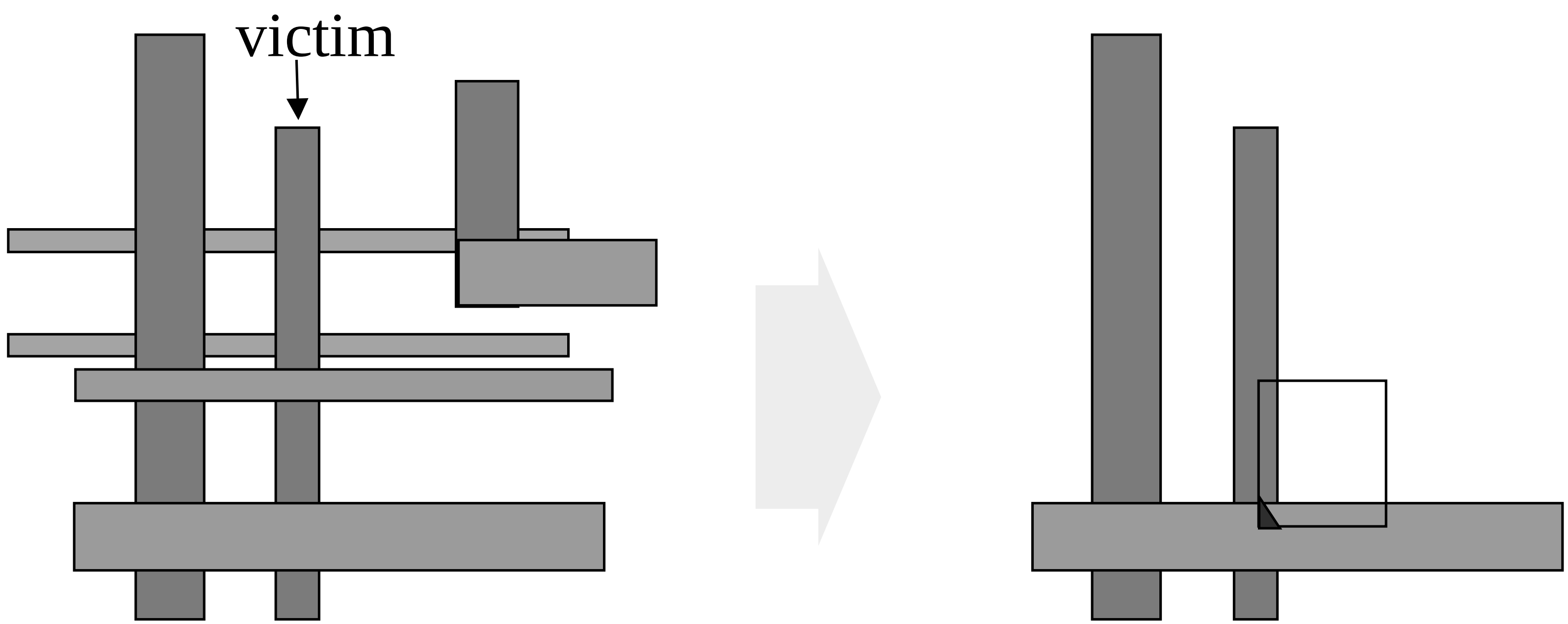

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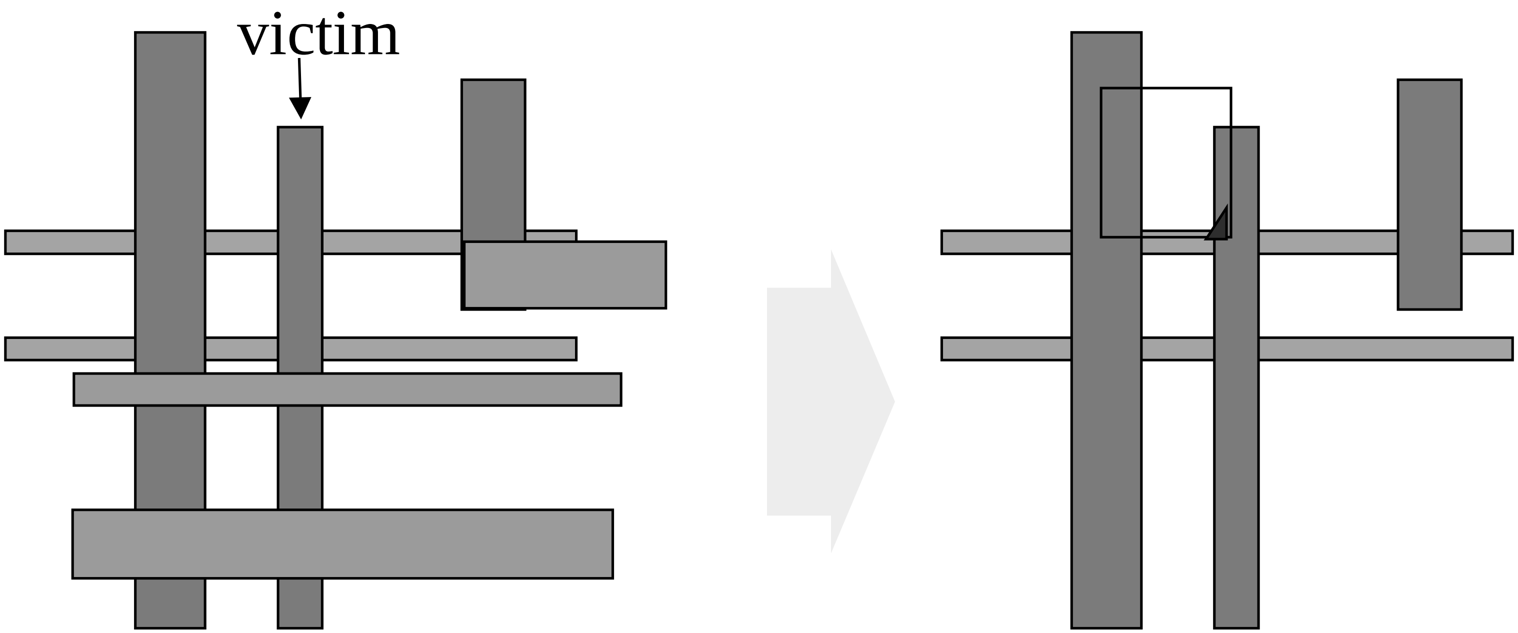

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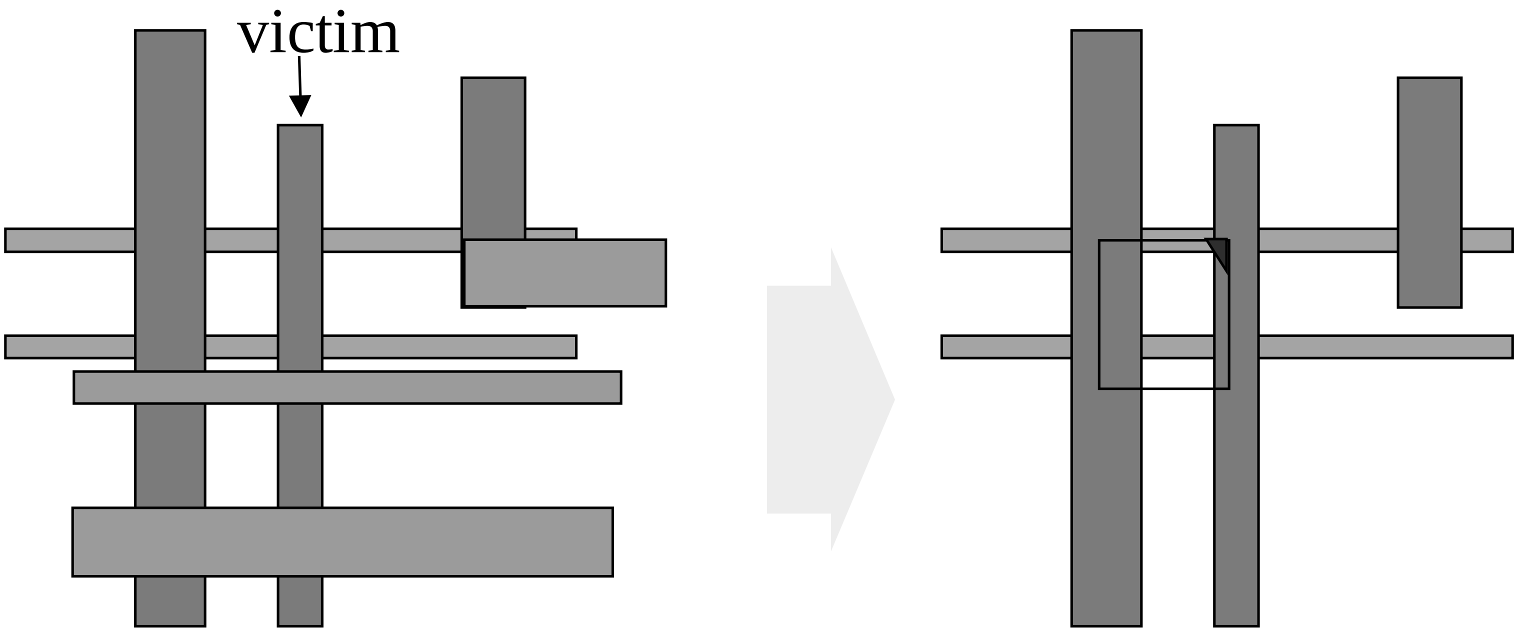

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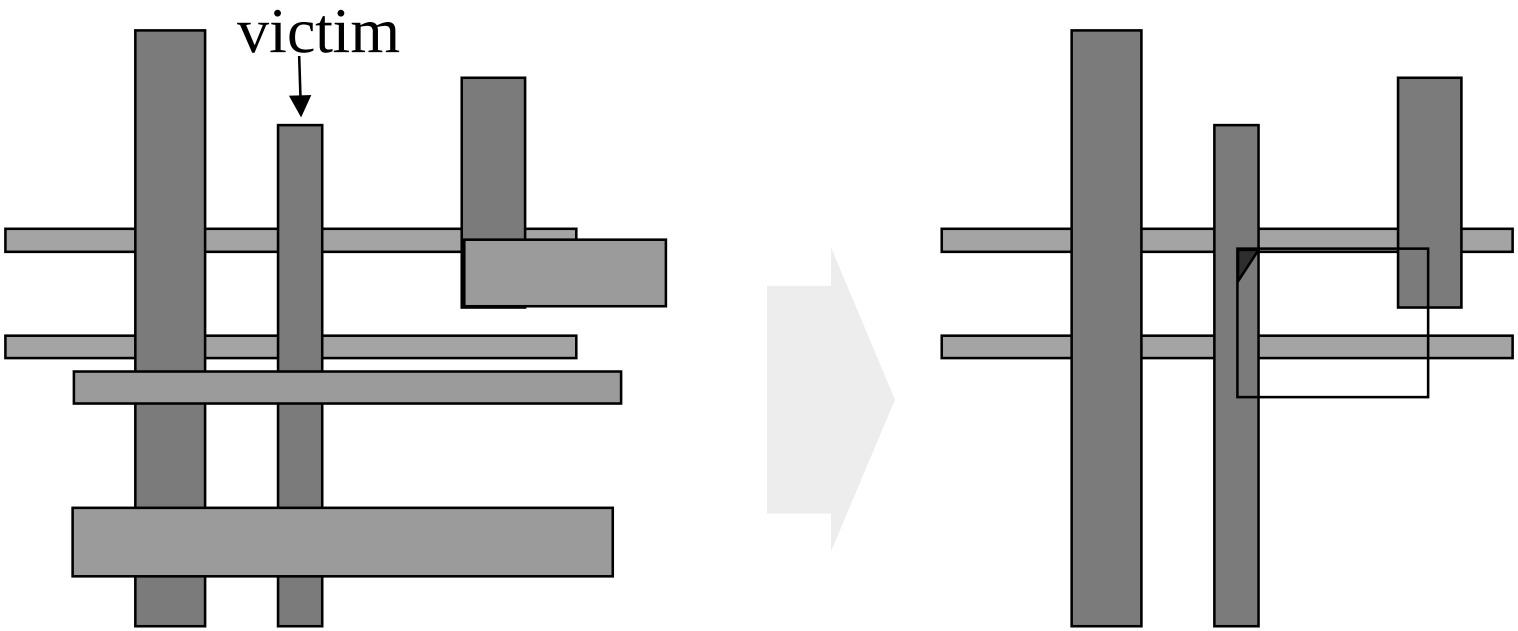

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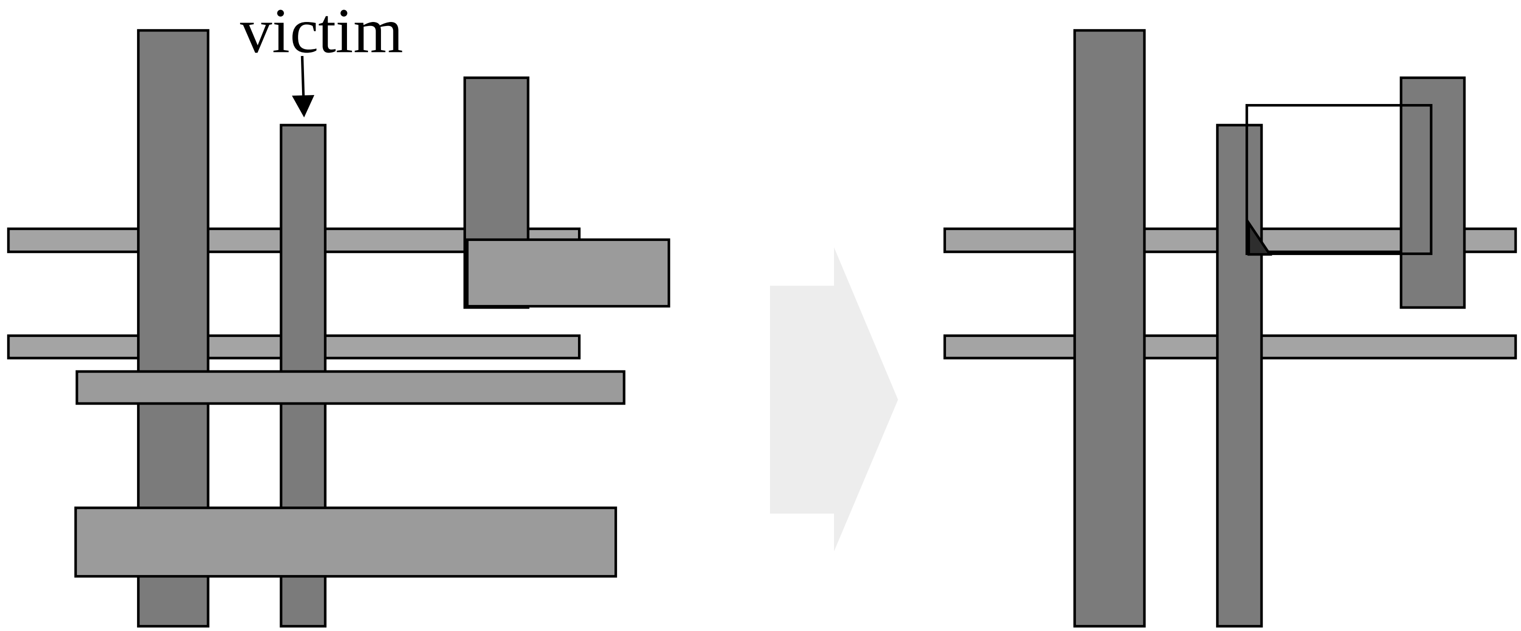

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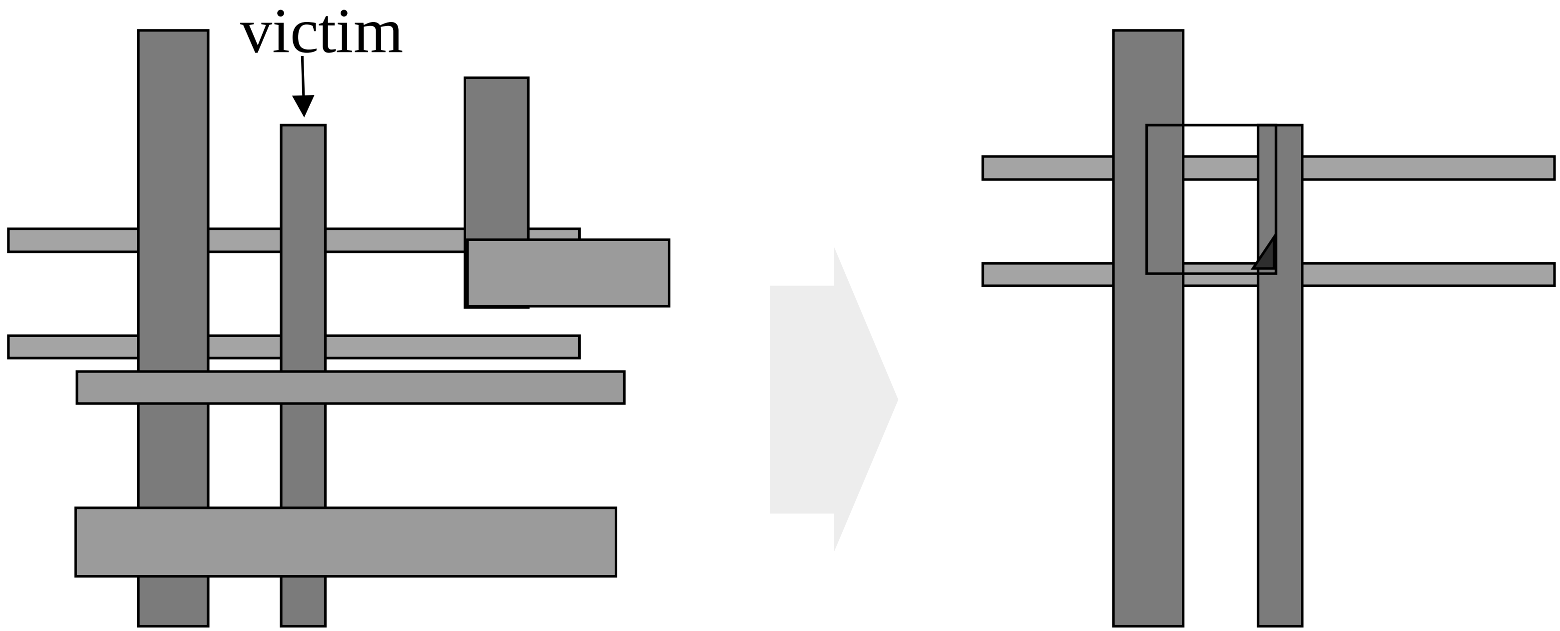

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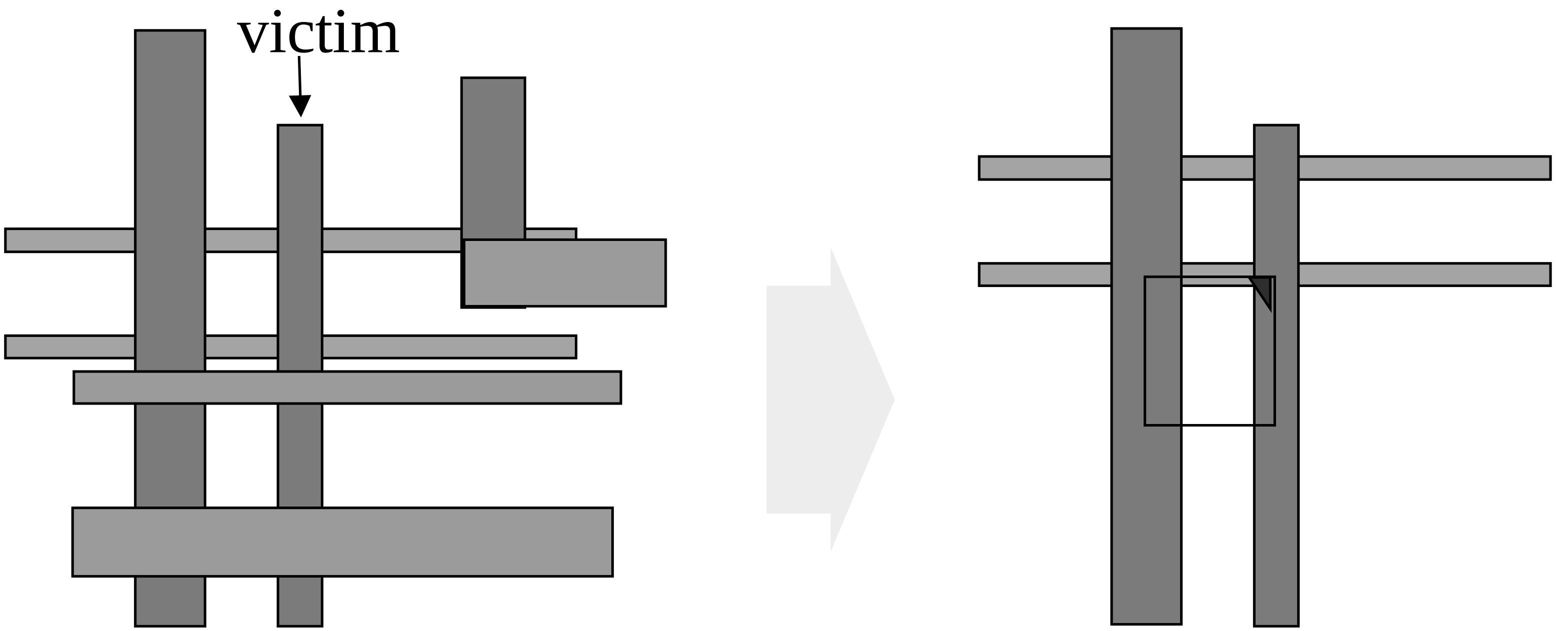

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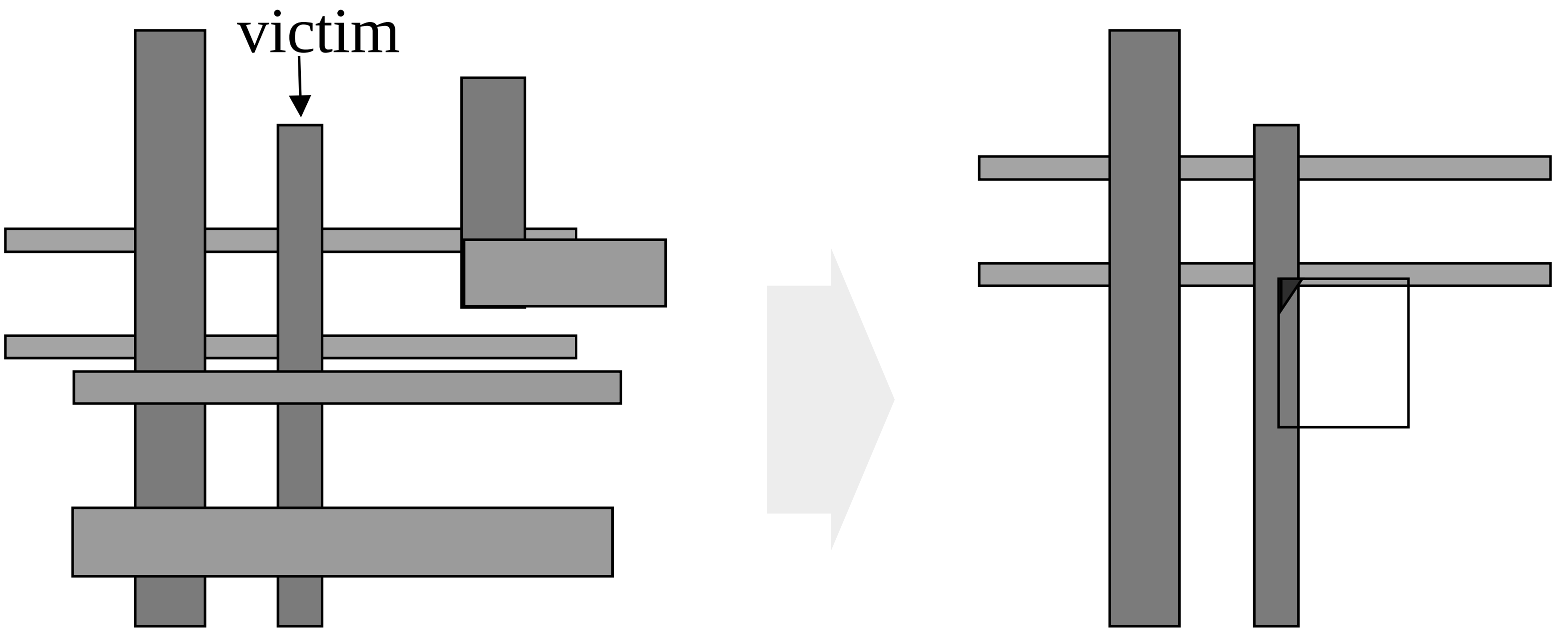

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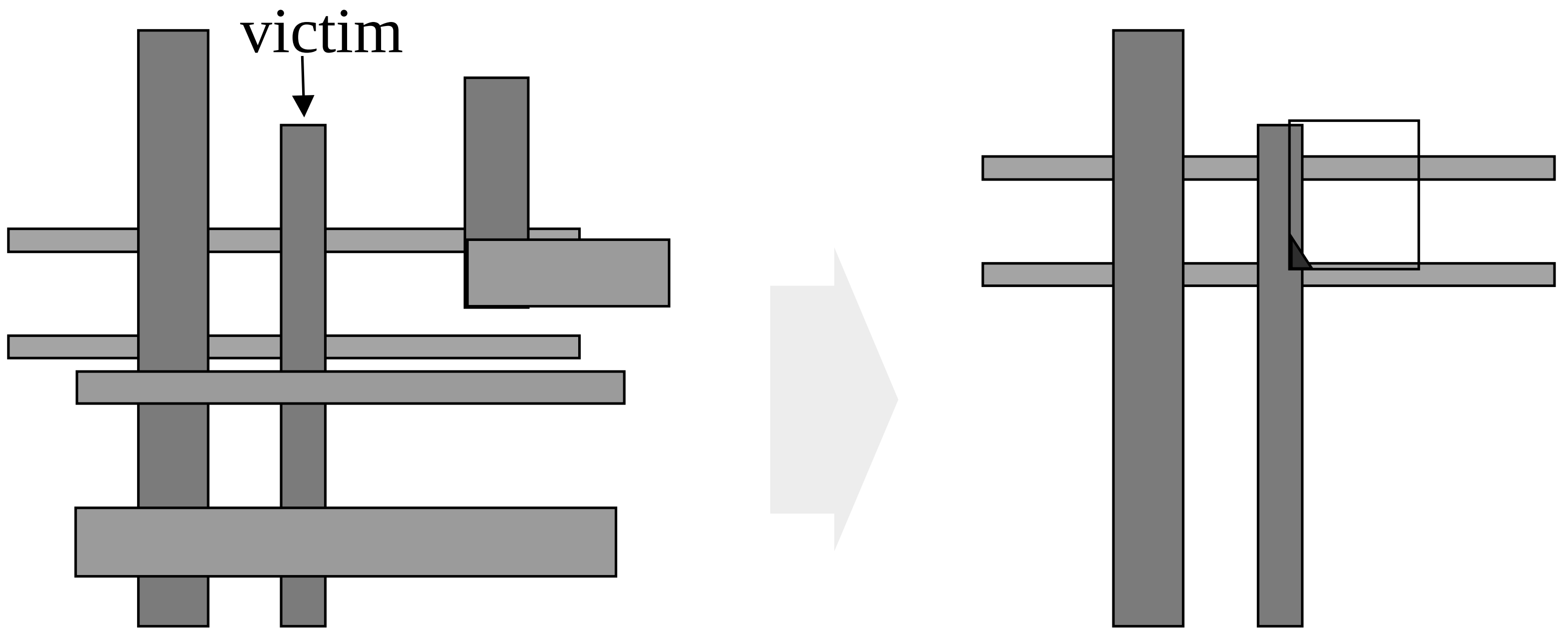


Count each crossover and crossunder.

Experimental Results

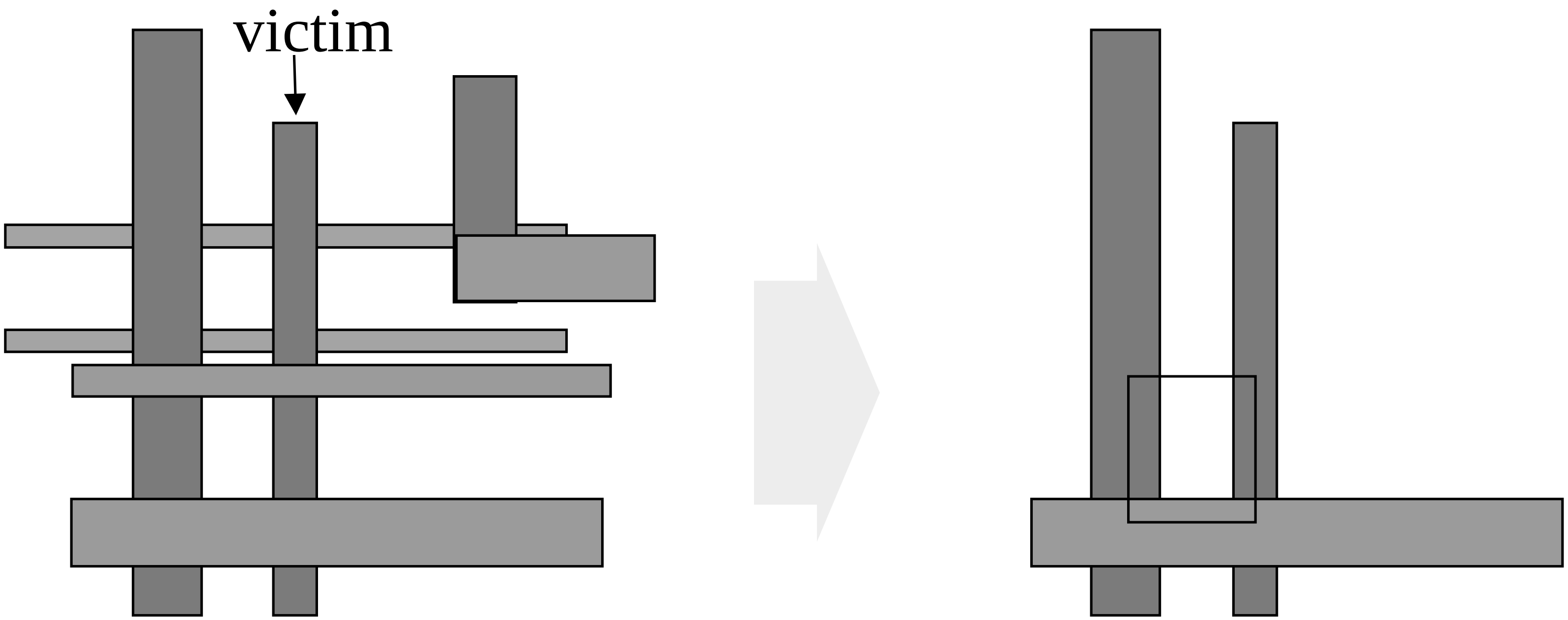
Good match in terms of lumpled capacitance!

Conclusions

- Five foundations are validated to guide and simplify capacitance extraction
- A simply 2 1/2-D extraction methodology is described
- It is accurate for current and near-term processes, and is used in Silicon Ensemble 5.0

Thanks

2 1/2-D algorithm



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Area and Fringe Capacitance Coefficients