Interconnect RC extraction

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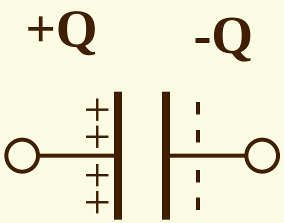
What's Capacitance?



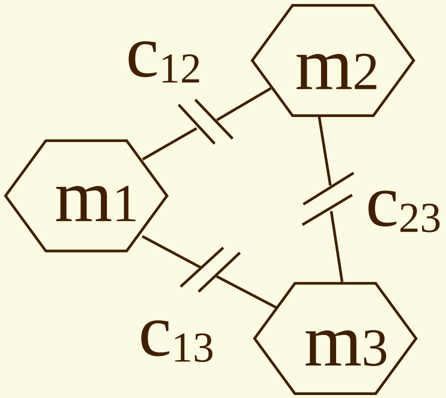
- **Simplest model: parallel-plate capacitor**
  - It has two parallel plates and homogeneous dielectric between them
  - The capacitance is
    - ε permittivity of dielectric
    - *A* area of plate
    - *d* distance between plates

$$C = \varepsilon \frac{A}{d}$$

  - The capacitance is the capacity to store charge
    - charge at each plate is
      - one is positive, the other is negative

$$Q = CV$$

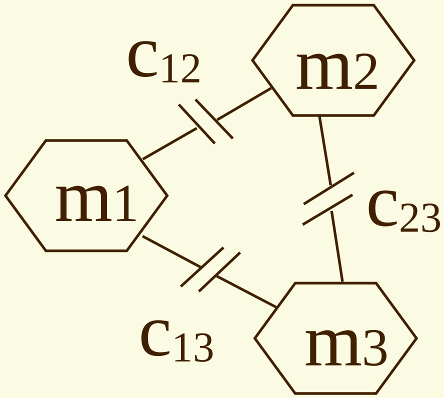
General Picture



- **For multiple conductors of any shapes and materials, and in any dielectric, there is a capacitance between any two conductors**
- **Each conductor has a resistance associated with it and is calculated using foundry-provided sheet-resistance tables.**
- **Resistance of a net is calculated independent of its neighbors.**

Capacitance Matrix

- **Capacitance is often written as a symmetric matrix**



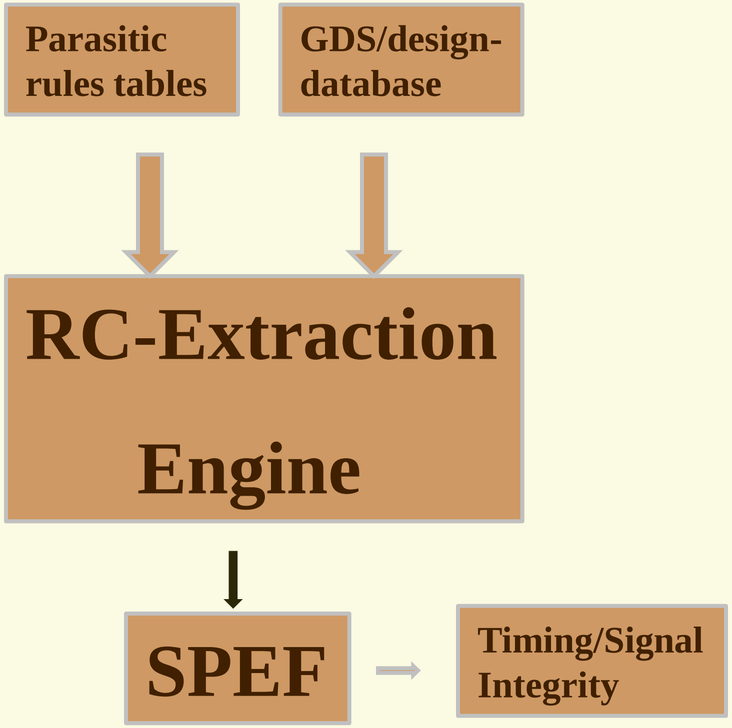
$$C = \begin{matrix} c_{11} & c_{12} & c_{13} \\ c_{21} & c_{22} & c_{23} \\ c_{31} & c_{32} & c_{33} \end{matrix}$$

- $c_{ii} = -\sum_{j=1}^{m} c_{ij} \, (j \neq i)$ **is the self-capacitance for a conductor**
  - *e.g.,* $c_{11} = c_{12} + c_{13}$

- **The charge is given by** $Q^m = C^{mm} (V^m)^T$
  - e.g., $q_1 = c_{11} v_1 - c_{12} v_2 - c_{13} v_3$
    $= c_{12}(v_1 - v_2) + c_{13}(v_1 - v_3)$

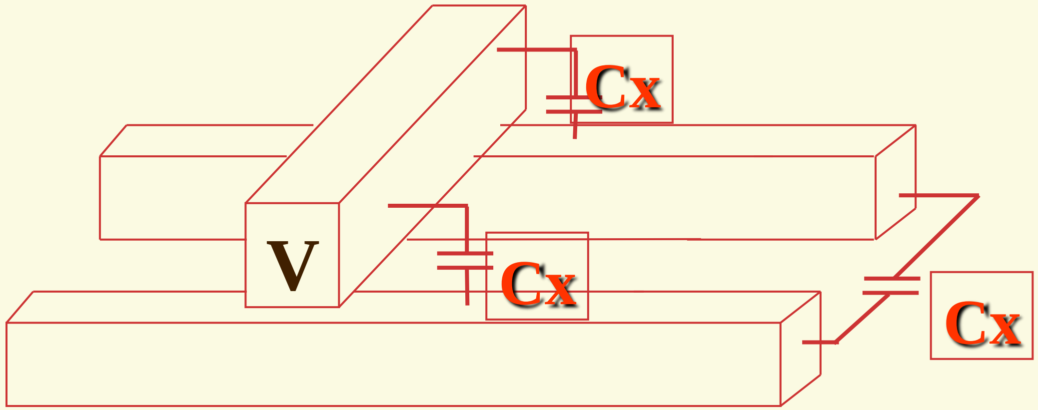
Application in VLSI Circuits

- **Conductors: metal wire, via, polysilicon, substrate**
- **Dielectrics: SiO_2 ,...**
- **Total cap for a wire**
  - delay, power
- **Mutual cap between wires**
  - signal integrity



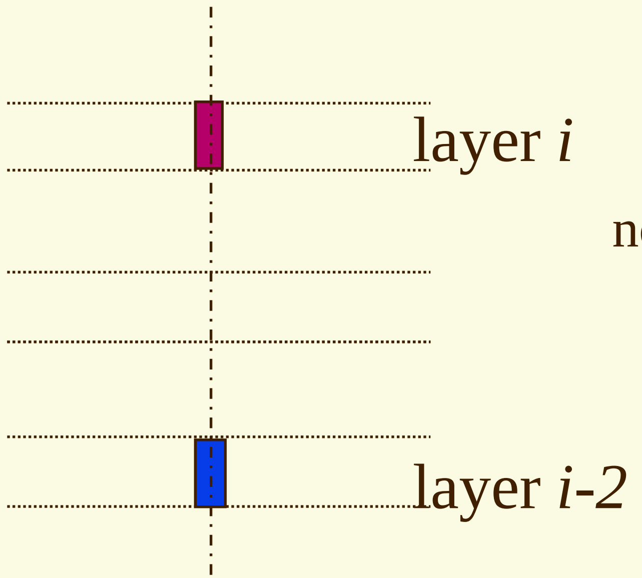
Characteristics of Capacitance

- **Coupling capacitance virtually exists only between adjacent wires or crossing wires but more pronounced between layers *i* and *i-2*/*i+2*.**



- **Capacitance can be pre-computed for a set of (localized) interconnect structures using a GOLDEN 3-D field solver extraction tool.**

Shielding Effect of Ground and Neighbors

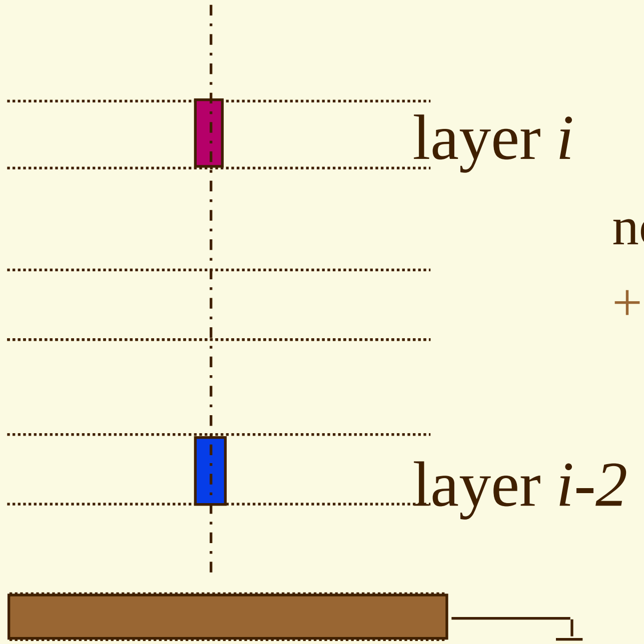


	$C_{i,i}$	$C_{i,i-2}$
no GND	458.4	130.1(28.4%)

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

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

Shielding Effect of Ground and Neighbors

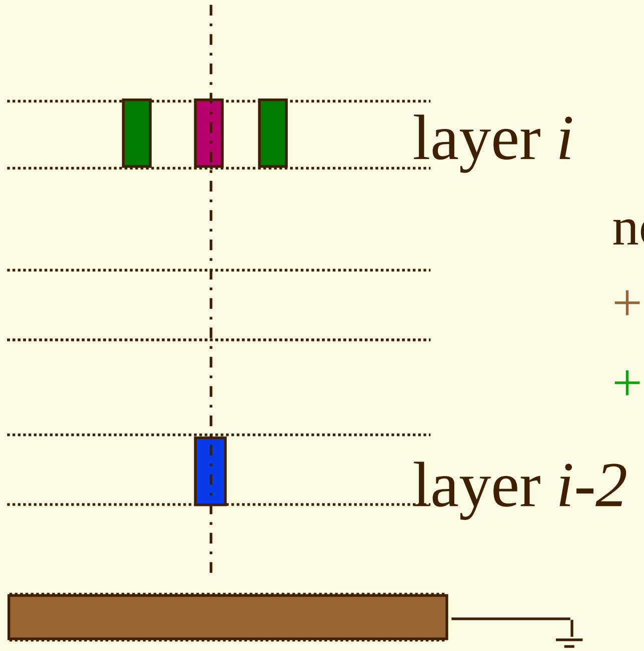


	$C_{i,i}$	$C_{i,i-2}$
no GND	458.4	130.1(28.4%)
+ GND	486.6	79.49(16.3%)

$C_{i,i}$ lumped capacitance for victim on layer i

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

Shielding Effect of Ground and Neighbors

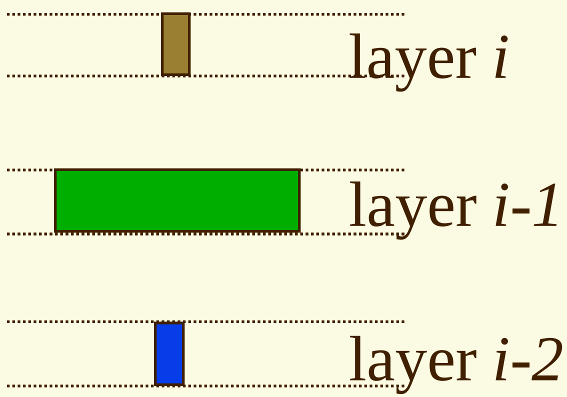


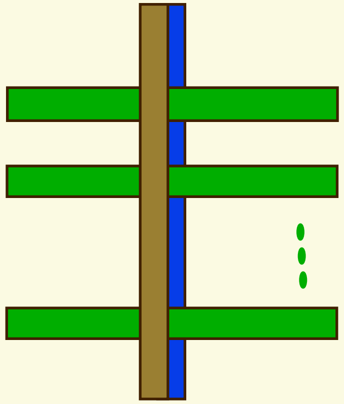
	$C_{i,i}$	$C_{i,i-2}$
no GND	458.4	130.1(28.4%)
+ GND	486.6	79.49(16.3%)
+ neighbors	1428	24.77(1.8%)

$C_{i,i}$ lumped capacitance for victim on layer i

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

Coupling between Layers i and i-2



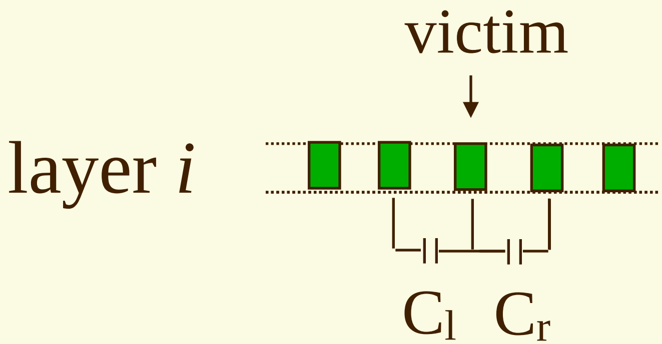


	--	2x	4x	8x	12x
$C_{i,i}$	486.6	534.5	581.3	622.2	635.9
$C_{i,i-2}$	79.49	48.45	21.99	3.47	2.47

$C_{i,i}$ lumped capacitance for victim on layer i

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

Effect of Non-immediate Neighbors (Second Aggressor)

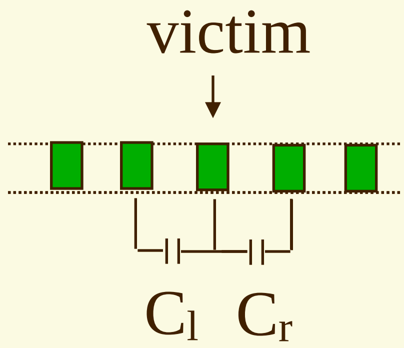


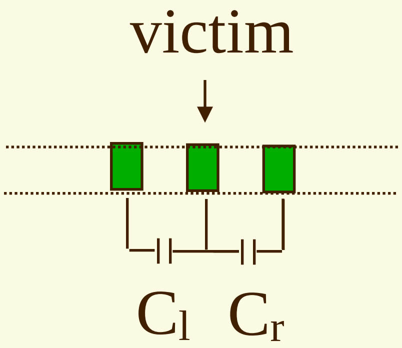
$C_{i,i}$	1436
C_l	616.6
C_r	616.5

$C_{i,i}$: lumped capacitance for victim.

Effect of Non-immediate Neighbors (Second Aggressor)

layer i

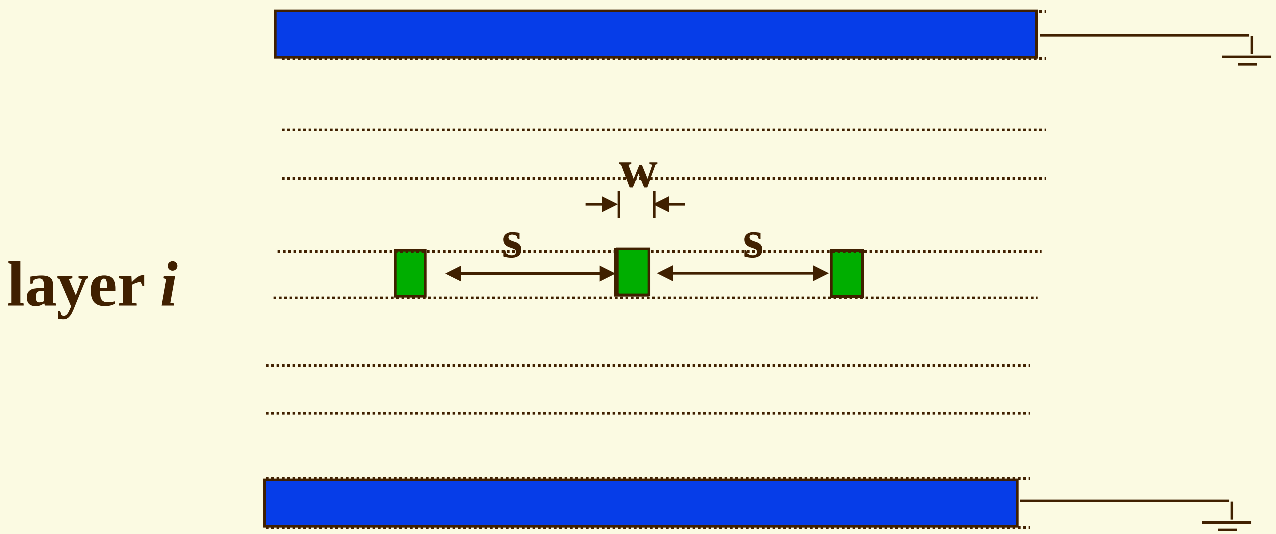




$C_{i,i}$	1436	1436(0%)
C_l	616.6	639.8(+3%)
C_r	616.5	639.5(+3%)

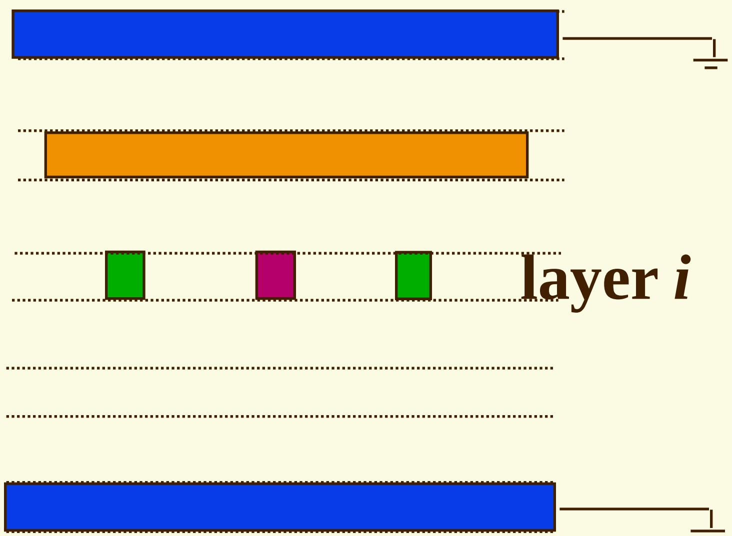
$C_{i,i}$: lumped capacitance for victim.

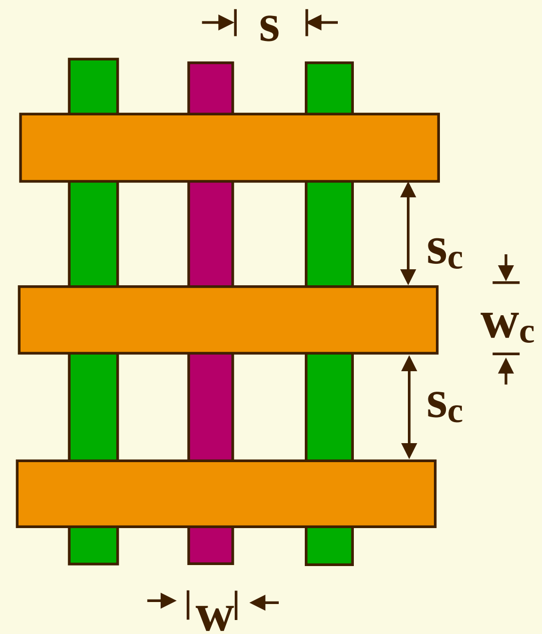
Table Generation for Lateral, Area and Fringe Capacitances



- Functions of (w,s)
- Pre-computed for per-side per unit-length

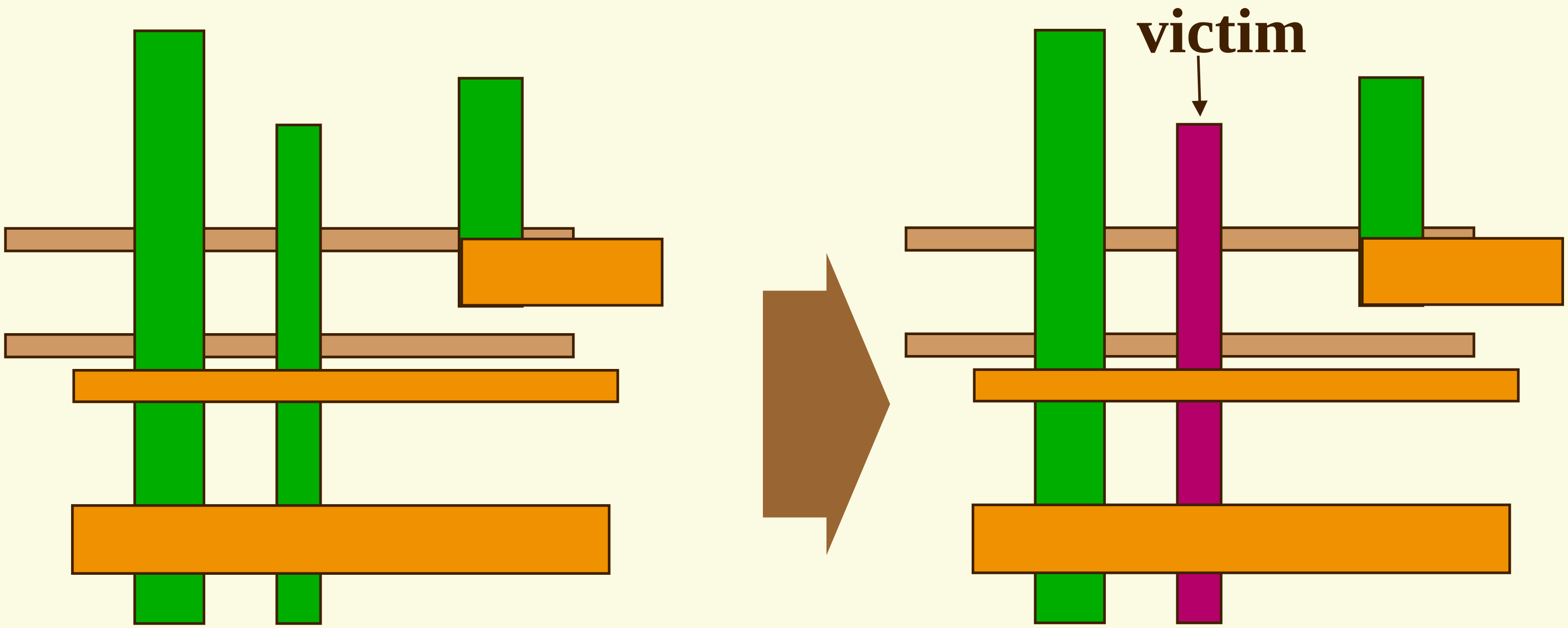
Table Generation for Crossing Capacitances





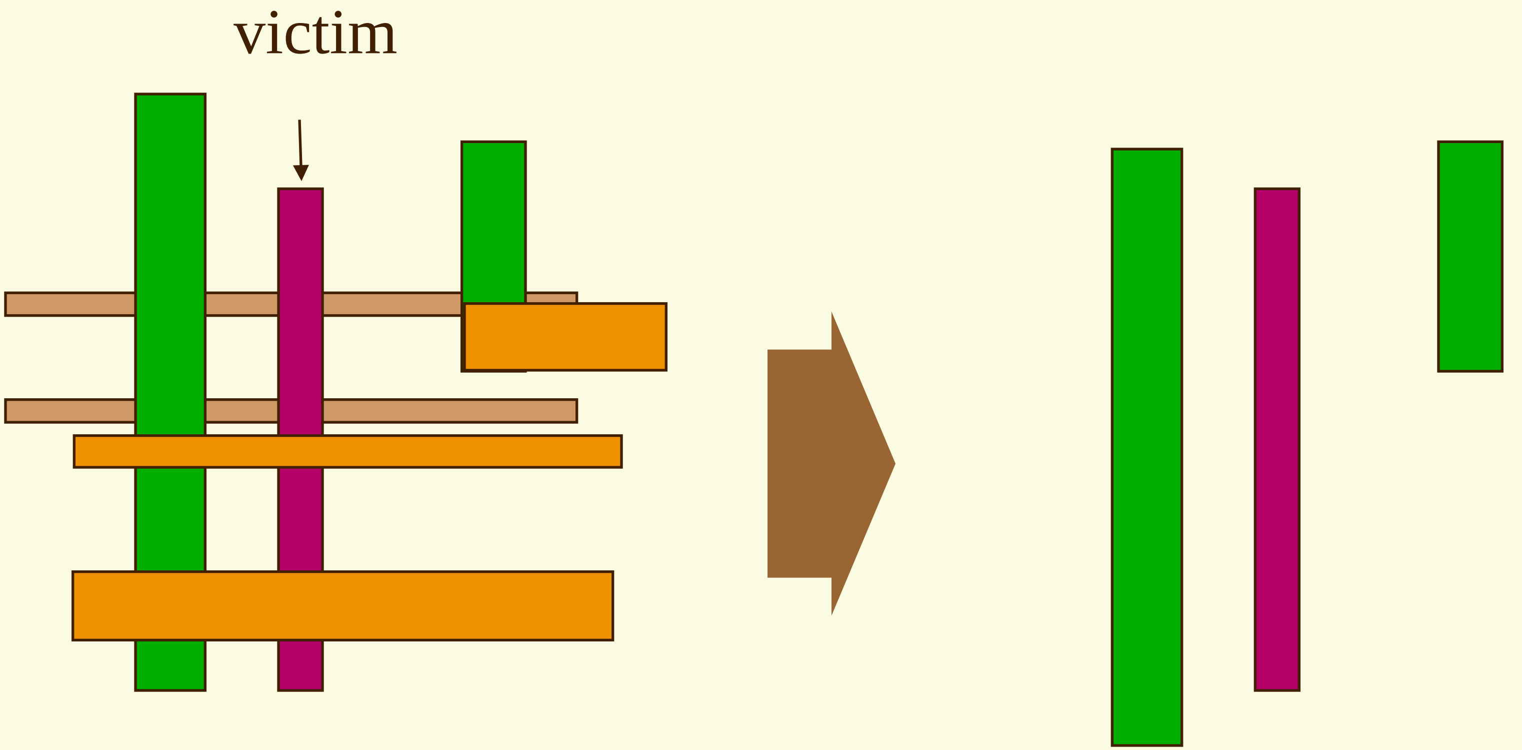
- Function of (w,s,w_c,s_c)

Illustration of Capacitance Computation

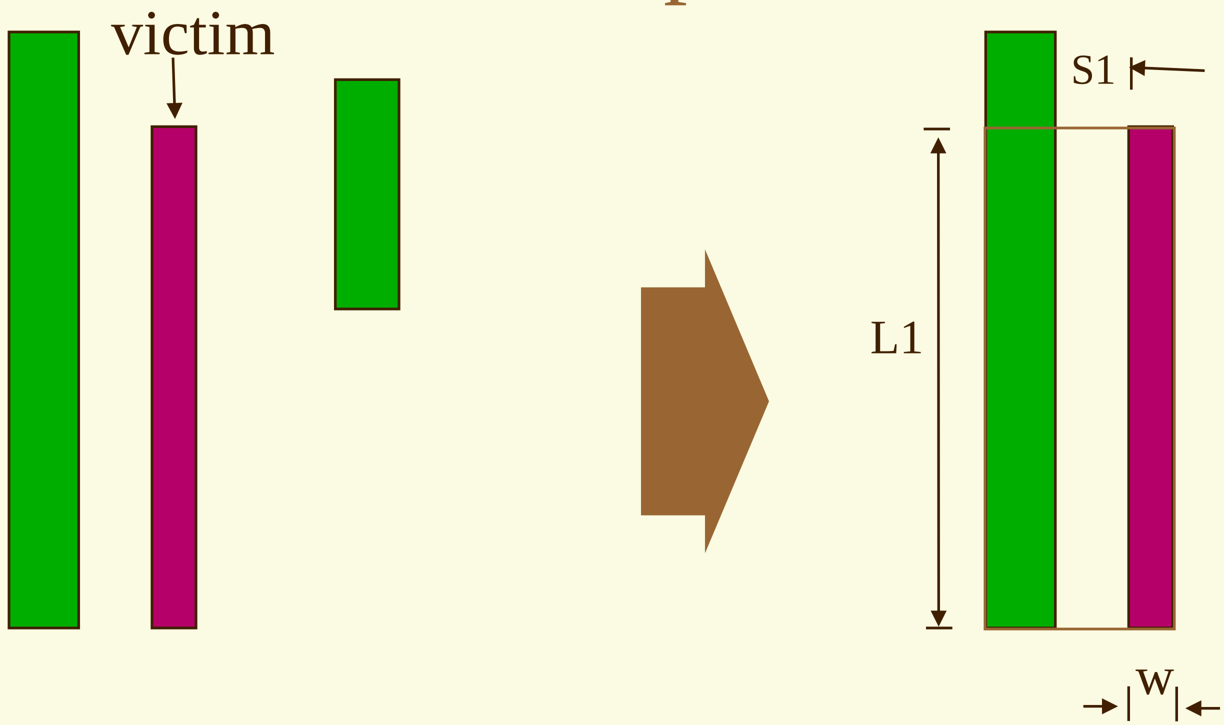


Compute the lumped cap for victim

❶Find Nearest Neighbors on Same Layer



❷Add in Per-Side Area, Fringe and Lateral Capacitances

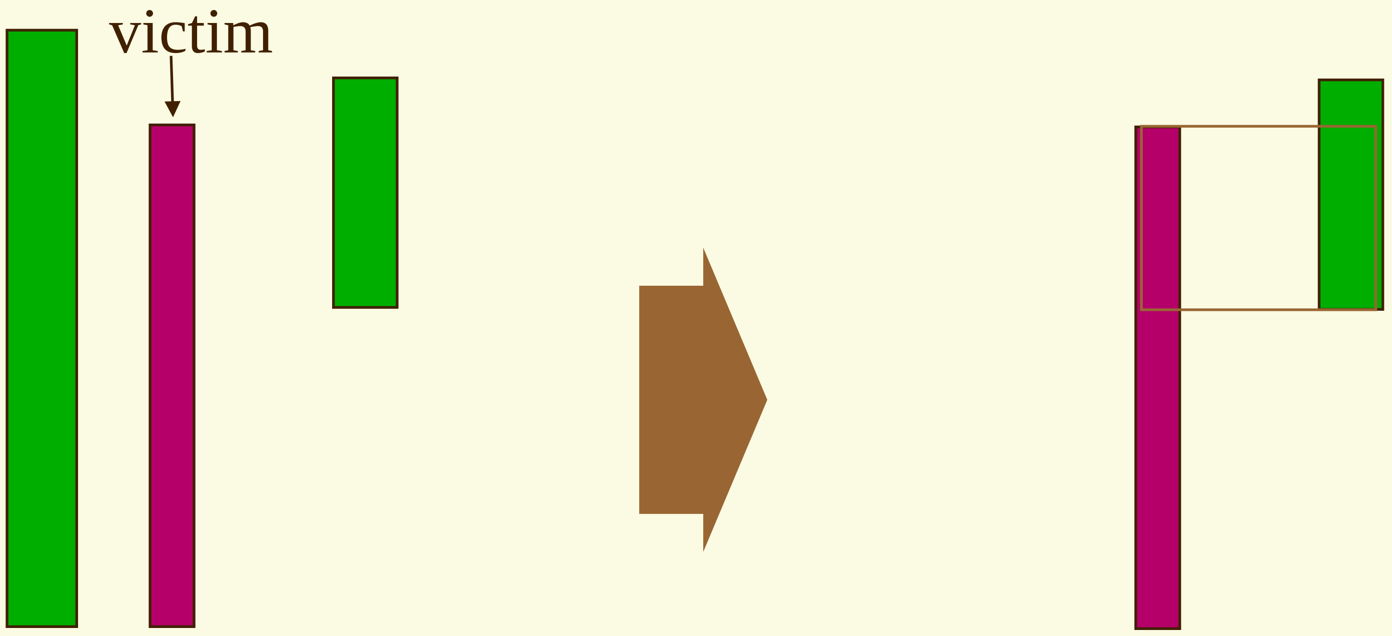


Per-side lateral capacitance = $C_L(w,s_1)$ * L1

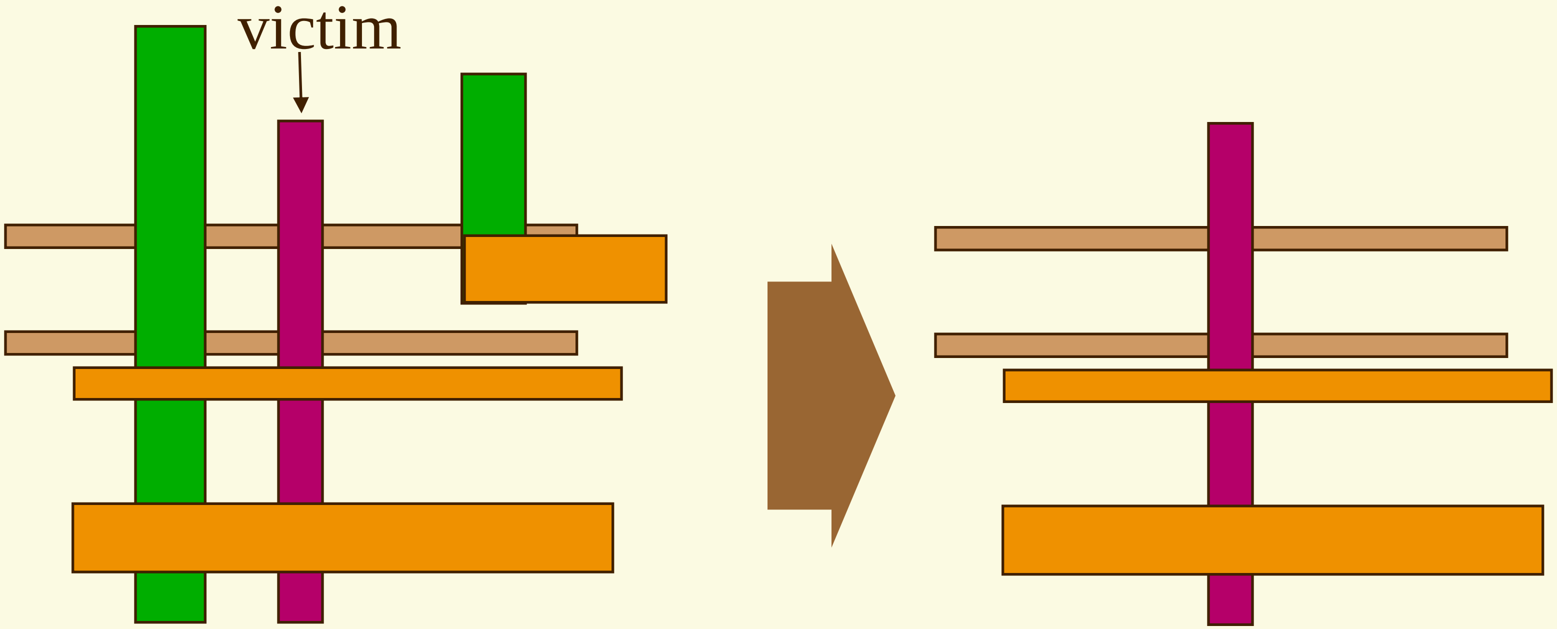
Per-side area capacitance = $C_A(w,s_1)$ * L1

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

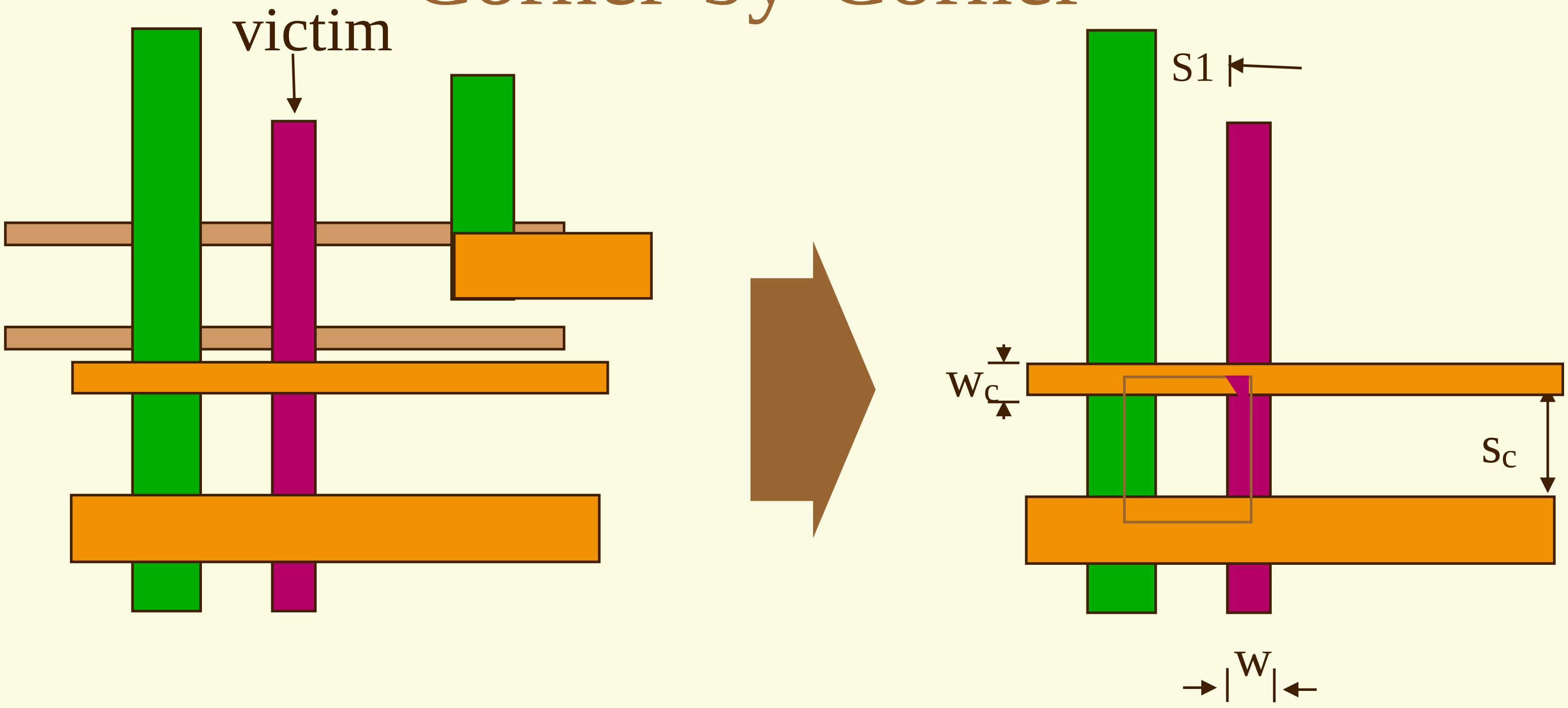
❷Add in Per-Side Area, Fringe and Lateral Capacitances



❸Find All Crossovers and Crossunders



❹ Add in Crossing Capacitances Corner-by-Corner



One-corner crossover correction = $C_{over}(w, s1, w_c, s_c)$

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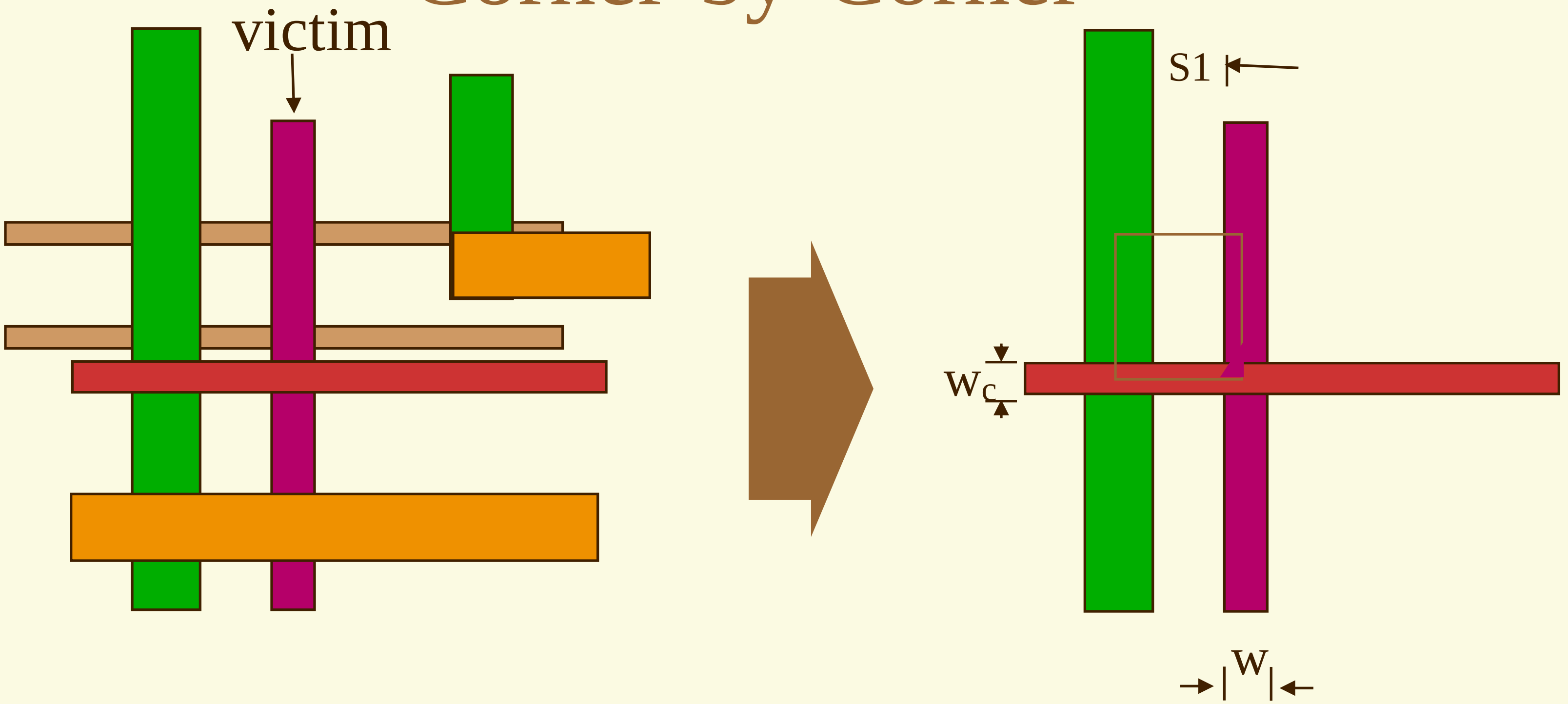
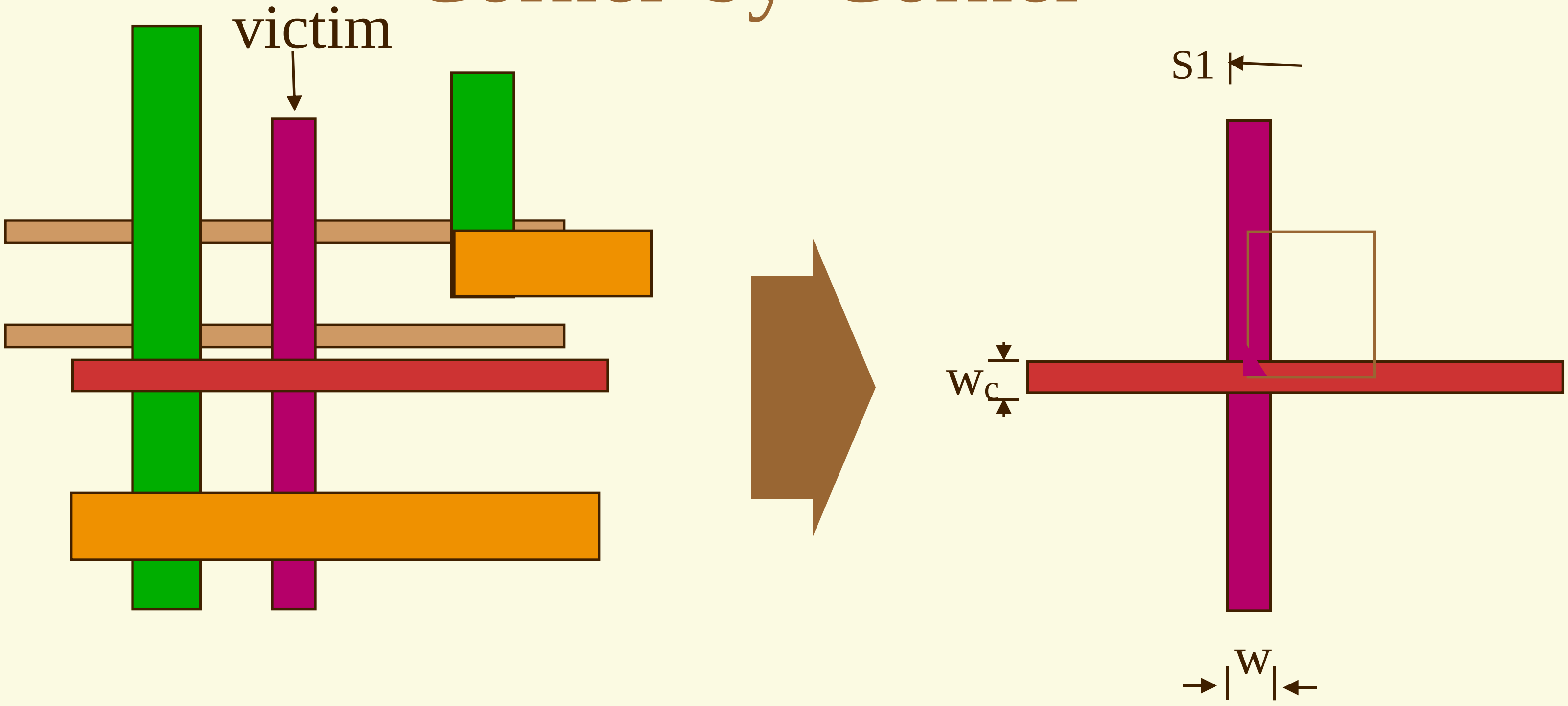


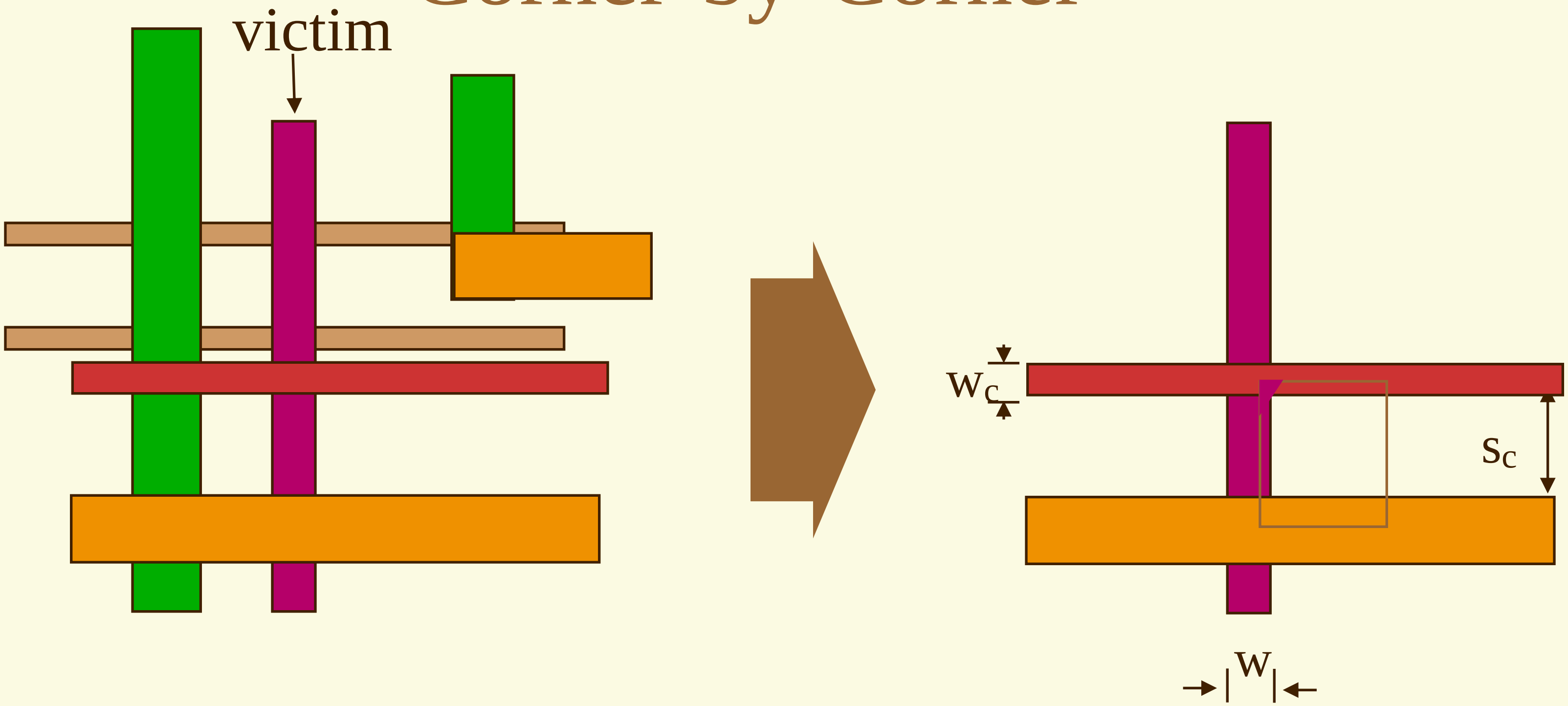
One-corner crossover correction = $C_{over}(w, s1, w_c, \infty)$

❹ Add in Crossing Capacitances Corner-by-Corner



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

❹ Add in Crossing Capacitances Corner-by-Corner



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

Summary of Capacitance Extraction

1. **Find nearest neighbors on the same layer**
2. **Add in per-side lateral, area and fringe capacitances w.r.t. each neighbor**
3. **Find all crossovers and crossunders**
4. **Add in crossing capacitances corner-by-corner w.r.t. each crossover and crossunder**

Sum of capacitance components in above steps is the lumped capacitance of the victim.

References

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