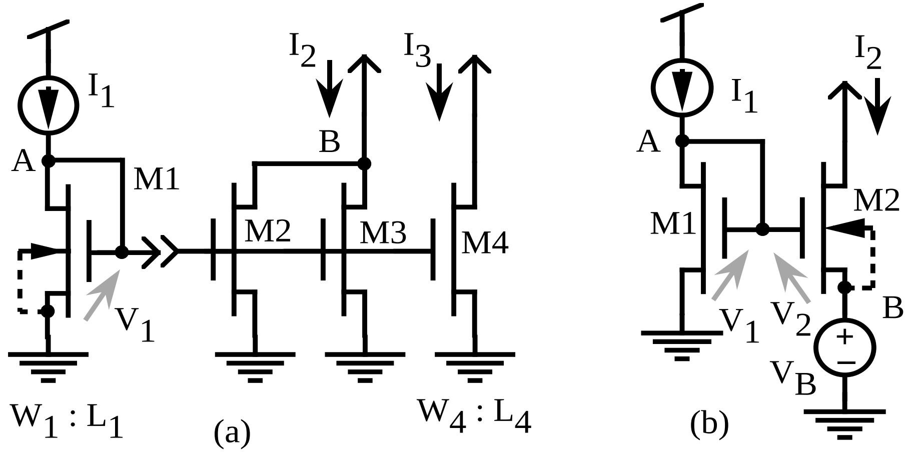
CURRENT MODE CIRCUITS IN SUBTHRESHOLD MOS

CURRENT MIRRORS AND SCALING



1. Multiple Transistors
-good-

2. Geometry scaling
-not so good-

$$I_2 = I_1 \exp\left(- \frac{\kappa V_B}{V_t} \right)$$

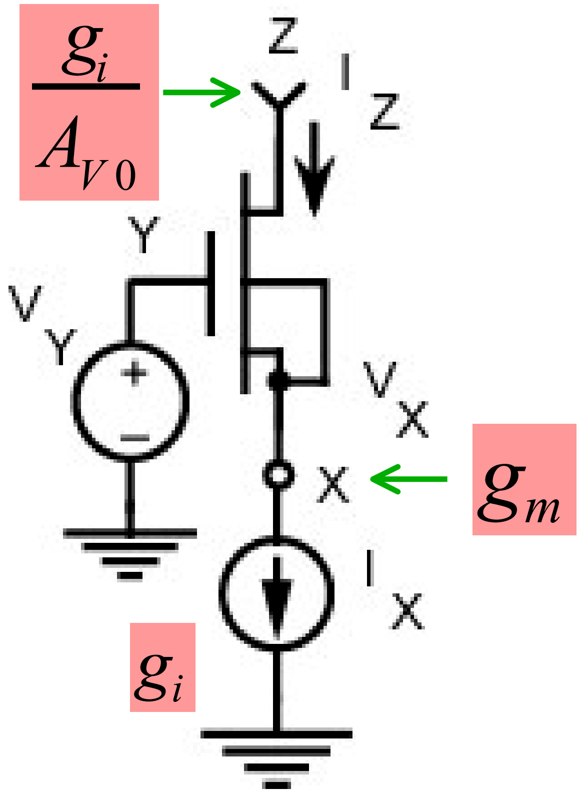
CURRENT CONVEYORS

- Minimal complexity circuits to manipulate currents and voltages
- Impedance converters -cascode mirrors-
- Useful as “neurons” in neuromorphic systems

DIFFUSIVE NETWORKS

- Useful in implementing attenuators and bias circuits (current dividers).
- Minimal complexity circuits for implementing local aggregation in neuromorphic vision systems.

1T CURRENT CONVEYOR (1TCC)



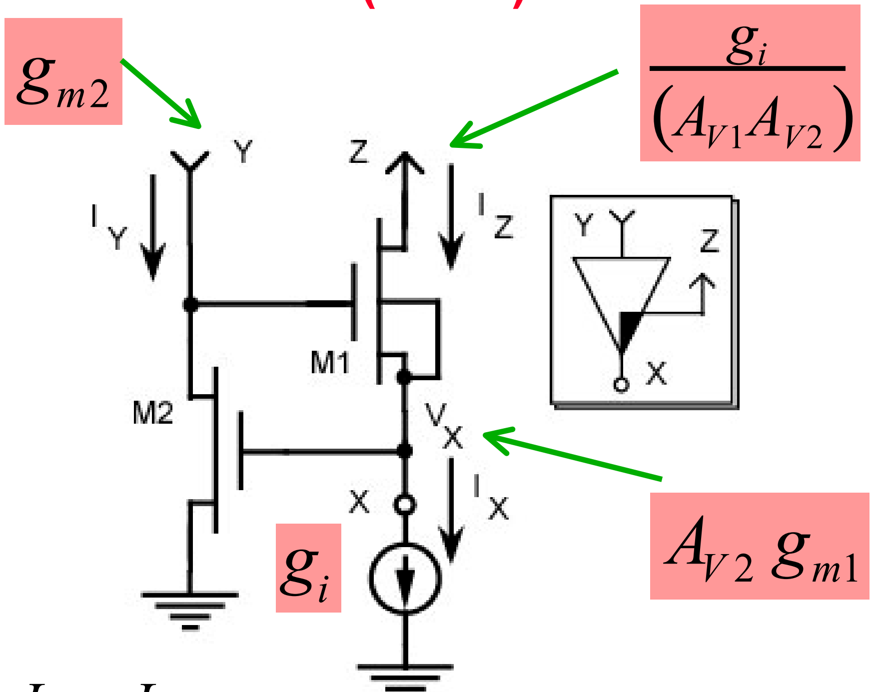
Note:

$$A_{v0} \equiv \frac{g_m}{g_d}$$

$$I_Z = I_X$$

$$V_X = \kappa V_Y + V_t \ln\left(\frac{I_X}{S\, I_O}\right)$$

2T CURRENT CONVEYOR (2TCC)

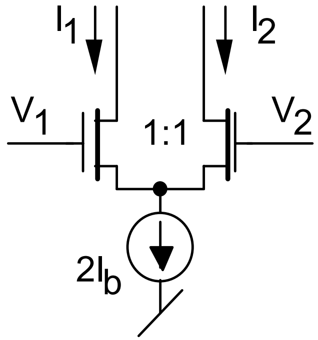


$$I_Z = I_X$$

$$V_X = \frac{V_t}{\kappa_2} \ln\left(\frac{I_Y}{S_2\, I_O}\right)$$

$$V_Y = \frac{V_t}{\kappa_1 \kappa_2} \ln\left(\frac{I_Y}{S_2\, I_O}\right) + \frac{V_t}{\kappa_1} \ln\left(\frac{I_X}{S_1\, I_O}\right)$$

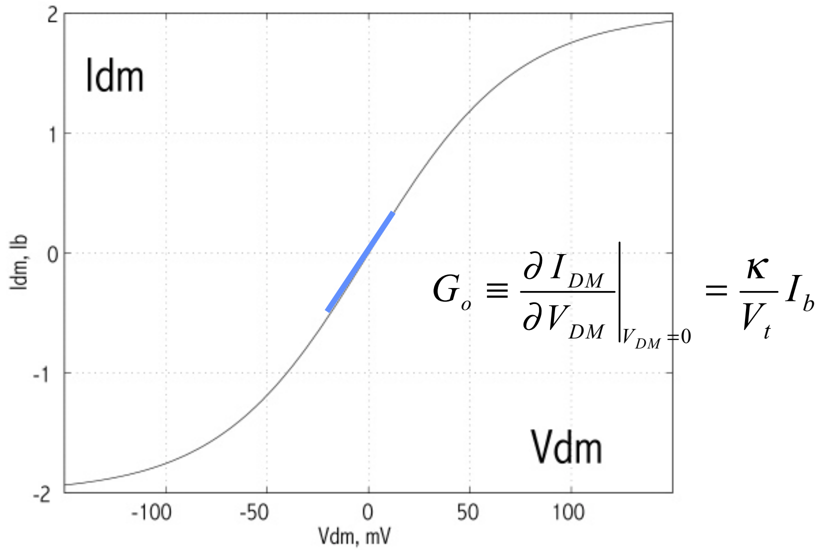
DIFFERENTIAL PAIR



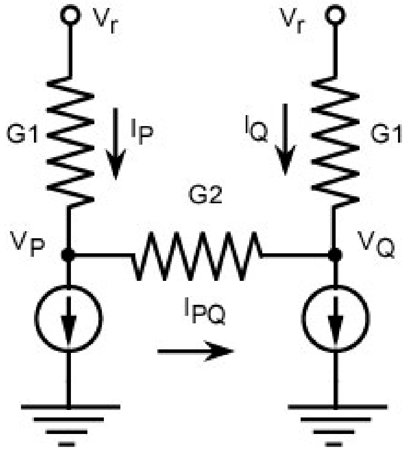
$$V_{DM} \equiv V_1 - V_2$$

$$I_{DM} \equiv I_1 - I_2$$

$$\boxed{I_{DM} = 2I_b \tanh\left(\frac{\kappa V_{DM}}{2V_t}\right)}$$



DIFFUSIVE NETWORKS



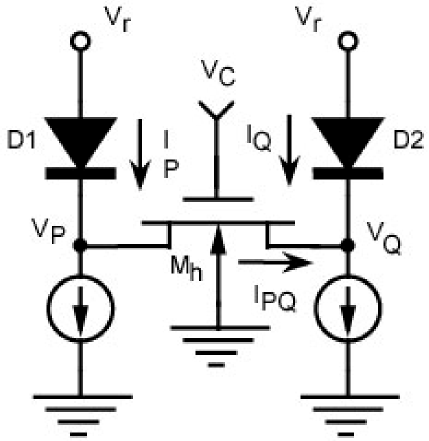
LINEAR

$$V_r - V_P = G_1\, I_P$$

$$V_r - V_Q = G_1\, I_Q$$

$$V_P - V_Q = G_2\, I_{PQ}$$

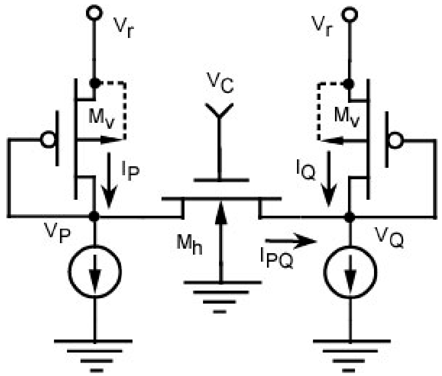
$$I_{PQ} = \left(\frac{G_1}{G_2}\right)\left(I_Q - I_P\right)$$



NON-LINEAR

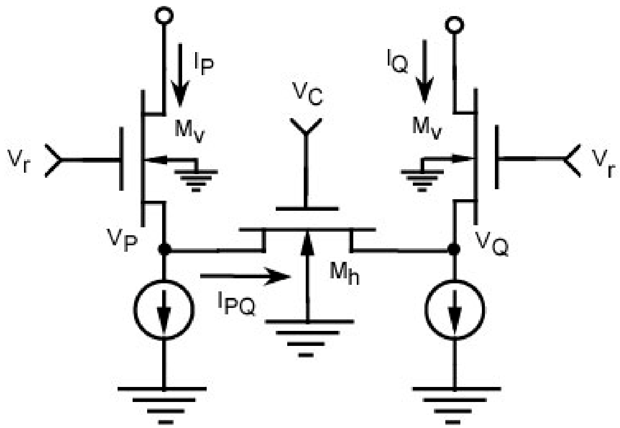
$$I_{PQ} = \left(\frac{S\, I_{n0}}{I_S}\right)\exp\left[\frac{\kappa_n V_C - V_r}{V_T}\right]\left(I_Q - I_P\right)$$

MOS TRANSISTOR ONLY NETWORKS



PMOS load-Diffusor

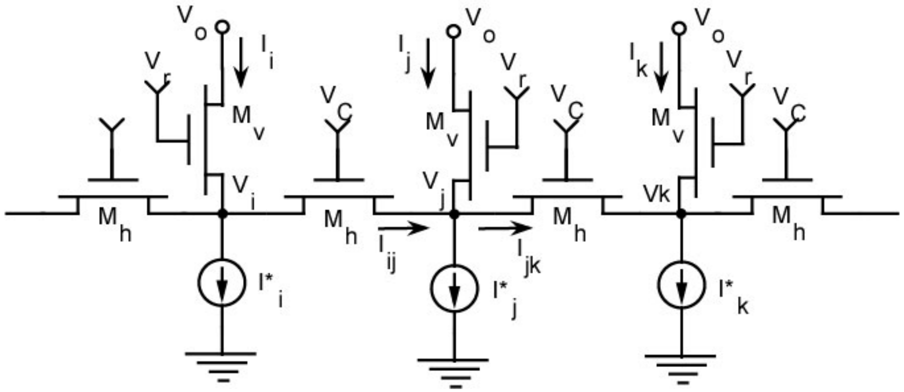
$$I_{PQ} = \left(\frac{S_h I_{n0}}{S_v I_{p0}}\right)\exp\left[\frac{\kappa_n V_C - \kappa_p V_r}{V_T}\right]\left(I_Q{}^{1/\kappa_p} - I_P{}^{1/\kappa_p}\right)$$



1TCC-Diffusor

$$I_{PQ} = \left(\frac{S_h}{S_v}\right)\exp\left[\frac{\kappa_n V_C - \kappa_n V_r}{V_T}\right]\left(I_Q - I_P\right)$$

1D SPATIAL AVERAGING NETWORK: Regularization Using Helmholtz Equation



Inputs: $I_i^*, I_j^*, I_k^*, I^*(x)$

Outputs: $I_i\,, I_j\,, I_k\,, I(x)$

At node V_j:

$$I_j^* = I_{ij} - I_{jk} + I_j$$

Using previous results, or using Translinear networks equations

$$I_j^* = I_j + \left(\frac{S_h}{S_v}\right)\exp\left(\kappa_n v_C - \kappa_n v_r\right)\left(2I_j - I_i - I_k\right)$$

Normalizing internode distances to unity we write the above on the continuum

$$I^*(x) = I(x) + \lambda \frac{d^2 I}{dx^2} \quad \text{where} \quad \frac{d^2 I}{dx^2} \approx 2I_j - I_i - I_k$$

Find the smooth function I(x) that best fits the data I(x) with the minimum energy in its first derivative.

λ The reqularization parameter: cost associated with energy in the derivative relative to the squared error of the fit to the data