CURRENT MODE CIRCUITS IN SUBTHRESHOLD MOS

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)

\[
\frac{g_i}{A_{V0}}
\]

Note:

\[
A_{v0} \equiv \frac{g_m}{g_d}
\]

\[
I_Z = I_X
\]

\[
V_X = \kappa V_Y + V_t \ln \left( \frac{I_X}{SI_o} \right)
\]
2T CURRENT CONVEYOR (2TCC)

\[ g_{m2} \]

\[ g_i \left( \frac{A_{V1} A_{V2}}{A_{V1} A_{V2}} \right) \]

\[ A_{V2} g_{m1} \]

\[ I_Z = I_X \]

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

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

DIFFERENTIAL PAIR

\[ V_{DM} \equiv V_1 - V_2 \]

\[ I_{DM} \equiv I_1 - I_2 \]

\[ I_{DM} = 2 I_b \tanh \left( \frac{kV_{DM}}{2V_t} \right) \]

\[ G_o \equiv \frac{\partial I_{DM}}{\partial V_{DM}} |_{V_{DM}=0} = \frac{k}{V_t} I_b \]
DIFFUSIVE NETWORKS

LINEAR

\[
V_r - V_P = G_1 I_P \\
V_r - V_Q = G_1 I_Q \\
V_P - V_Q = G_2 I_{PQ}
\]

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

NON-LINEAR

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

MOS TRANSISTOR ONLY NETWORKS

PMOS load-Diffusor

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

1TCC-Diffusor

\[
I_{PQ} = \left( \frac{S_h}{S_v} \right) \exp \left[ \frac{\kappa_n V_C - \kappa_n V_r}{V_T} \right] (I_Q - I_P)
\]
1D SPATIAL AVERAGING NETWORK: Regularization Using Helmholtz Equation

\[
I_j^* = I_j - I_{jk} + I_j
\]

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

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

At node \( V_j \):

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

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

\[
I^*(x) = I(x) + \lambda \frac{d^2 I}{dx^2}
\]

where \( \frac{d^2 I}{dx^2} \approx 2I_j - I_i - I_k \)

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

\( \lambda \)

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