Spindles

Sara Steele, after Golomb, Wang, & Rinzel (1996)


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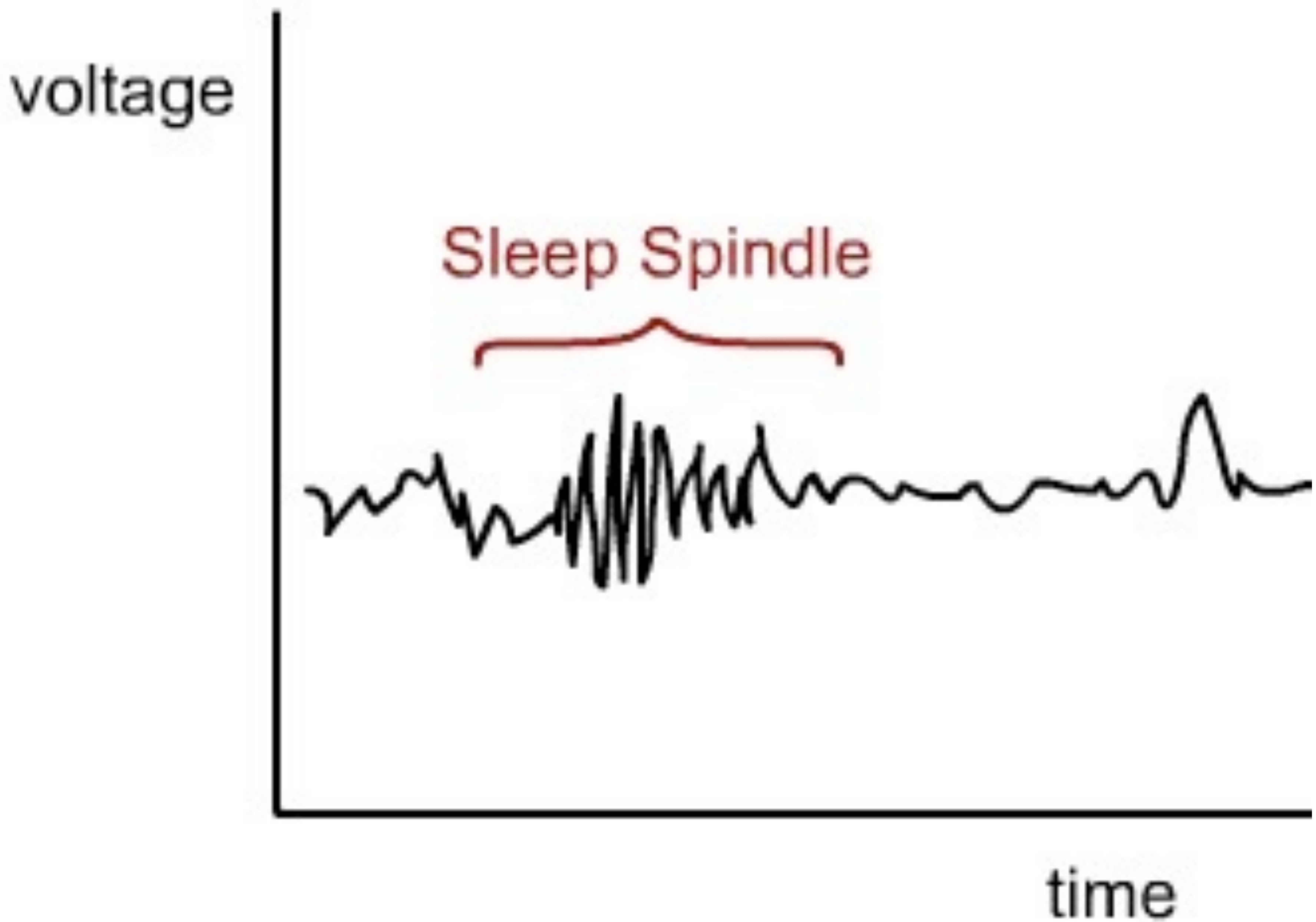
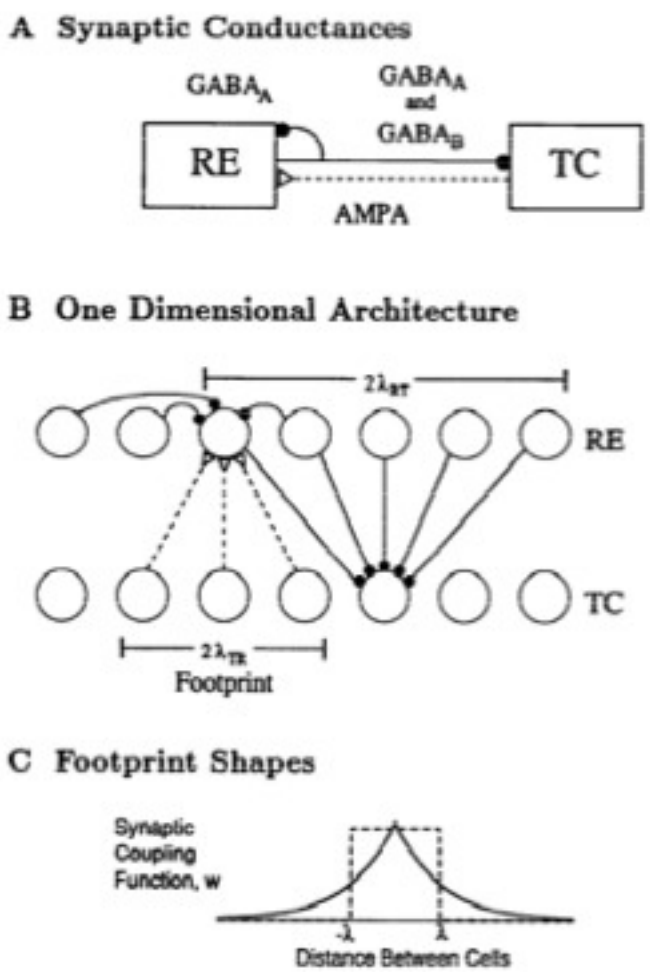
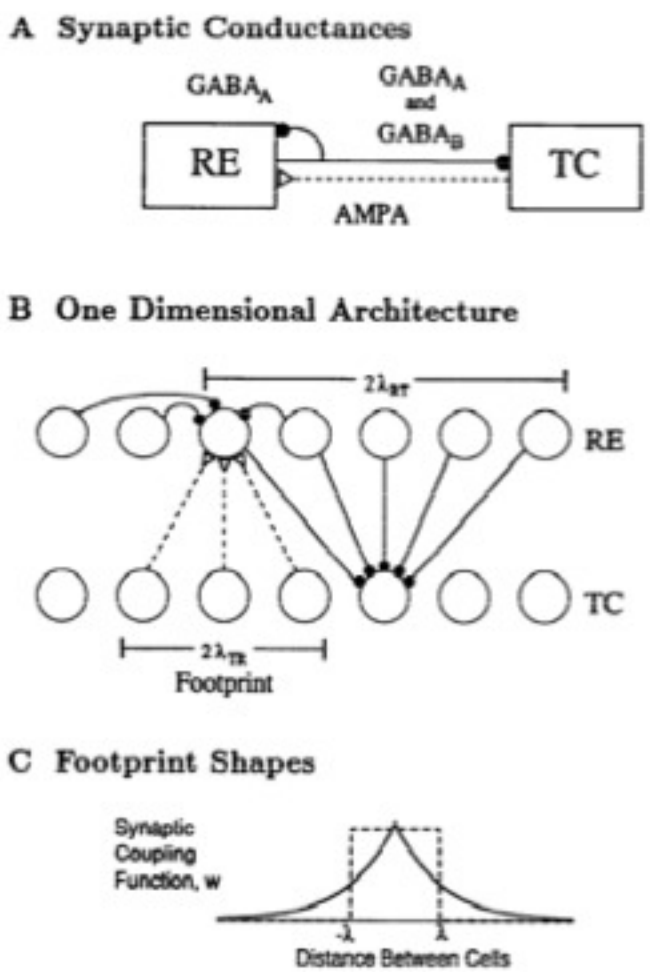
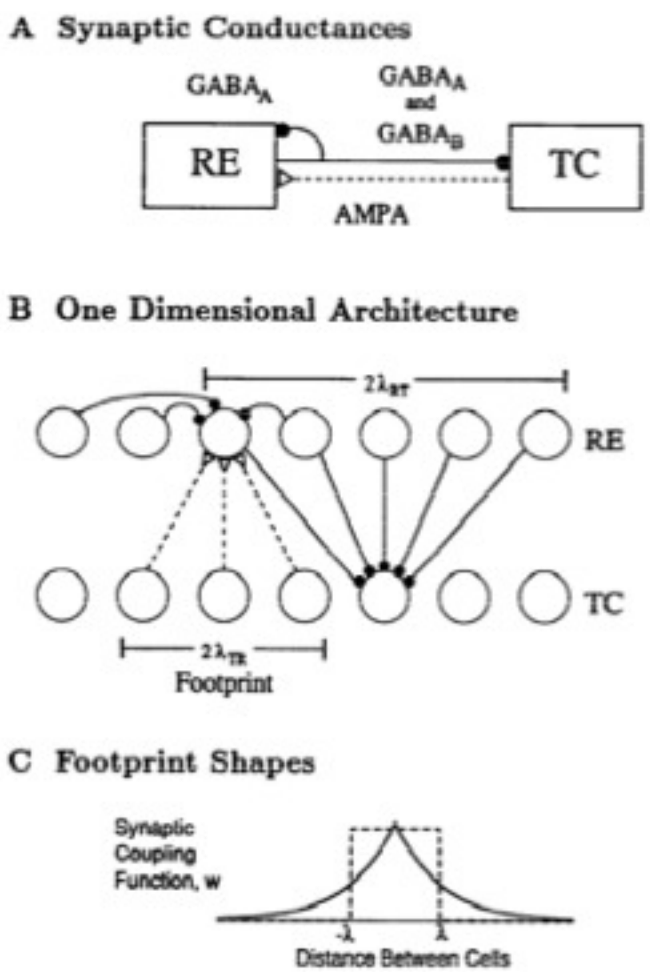

voltage
Sleep Spindle
time


A Synaptic Conductances
GABA$_A$
GABA$_A$ and GABA$_B$
RE
TC
AMPA
B One Dimensional Architecture
$2\lambda_{RT}$
RE
TC
$2\lambda_{TR}$
Footprint
C Footprint Shapes
Synaptic Coupling Function, w
$-\lambda$
λ
Distance Between Cells

Reticular (RE) cells:



$$C\frac{\mathrm{d}V_i}{\mathrm{d}t} = -I_{\mathrm{Ca\text{-}T}}(V_i, h_i) - I_{\mathrm{KL}}(V_i) - I_{\mathrm{NL}}(V_i)$$
$$- I_{\mathrm{AHP}}(V_i, m_{\mathrm{AHP}_i}) - I_{\mathrm{AMPA}}(V_i, \{s_{Pj}\}) - I^{RR}_{\mathrm{GABA_A}}(V_i, \{s_{Aj}\})$$



Reticular (RE) cells:

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Thalamocortical (TC) cells:

$$C\frac{\mathrm{d}V_i}{\mathrm{d}t} = -I_{\mathrm{Ca\text{-}T}}(V_i, h_i) - I_{\mathrm{KL}}(V_i) - I_{\mathrm{NL}}(V_i) - I_{\mathrm{h}}(V_i, r_i)$$
$$- I_{\mathrm{GABA_A}}(V_i, \{s_{Aj}\}) - I_{\mathrm{GABA_B}}(V_i, \{s_{Bj}\})$$

Both populations

Potassium leak current $I_{KL} = g_{KL}(V - V_K)$

Nonspecific leak current $I_{NL} = g_{NL}(V - V_{NL})$

$I_{Ca\text{-}T}$.

$$I_{Ca\text{-}T}(V, h) = g_{Ca}\, m_\infty^2(V) h (V - V_{Ca})$$

$$\frac{dh}{dt} = [h_\infty(V) - h]/\tau_h(V)$$

$$m_\infty(V) = \{1 + \exp[-(V - \theta_m)/\sigma_m]\}^{-1}$$

$$h_\infty(V) = \{1 + \exp[-(V - \theta_h)/\sigma_h]\}^{-1}$$

RE cell specific

RE cell specific

INTRINSIC CURRENTS.

I_{AHP}.

$$I_{\mathrm{AHP}}(V, m_{\mathrm{AHP}}) = g_{\mathrm{AHP}} m_{\mathrm{AHP}}(V - V_{\mathrm{K}})$$

$$\frac{\mathrm{d}[\mathrm{Ca}]}{\mathrm{d}t} = -\nu I_{\mathrm{Ca\text{-}T}} - \gamma[\mathrm{Ca}]$$

$$\frac{\mathrm{d}m_{\mathrm{AHP}}}{\mathrm{d}t} = \alpha[\mathrm{Ca}](1 - m_{\mathrm{AHP}}) - \beta m_{\mathrm{AHP}}$$

RE cell specific

INTRINSIC CURRENTS.

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SYNAPTIC CURRENTS.

AMPA current I_{AMPA} from TC to RE cells.

$$I_{\mathrm{AMPA}}(V, \{s_{Pj}\}) = g_{\mathrm{AMPA}}(V - V_{\mathrm{AMPA}}) \sum_{j=1}^{N} w_{\mathrm{TR}}(i - j) s_{Pj}$$

AMPA gating variable.

$$\frac{\mathrm{d}s_{Pj}}{\mathrm{d}t} = k_{fP} s_{\infty}(V)(1 - s_{Pj}) - k_{rP} s_{Pj}$$

$$s_{\infty}(V) = \{1 + \exp[-(V - \theta_s)/\sigma_s]\}^{-1}$$

$GABA_A$ current $I^{RR}_{GABA_A}$ from RE to RE cells.

$$I^{RR}_{\mathrm{GABA_A}}(V, \{s_{Aj}\}) = g^{RR}_{\mathrm{GABA_A}}(V - V_{\mathrm{GABA_A}}) \sum_{j=1}^{N} w_{RR}(i - j) s_{Aj}$$

$GABA_A$ gating variable.

$$\frac{\mathrm{d}s_{Aj}}{\mathrm{d}t} = k_{fA} s_{\infty}(V_j)(1 - s_{Aj}) - k_{rA} s_{Aj}$$

$$s_{\infty}(V) = \{1 + \exp[-(V - \theta_s)/\sigma_s]\}^{-1},$$

TC cell specific

TC cell specific

Hyperpolarization-activated cation current (sag) I_h.

$$I_h(V, r) = g_h r(V - V_h)$$

$$\frac{dr}{dt} = [r_\infty(V) - r]/\tau_{sag}(V)$$

$$r_\infty(V) = \{1 + \exp[-(V - \theta_{sag})/\sigma_{sag}]\}^{-1}$$

$$\tau_{sag}(V) = 20 + 1{,}000/\{\exp[(V + 71.5)/14.2] + \exp[-(V + 89.0)/11.6]\}$$

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SYNAPTIC CURRENTS.

$GABA_A$ current I_{GABA_A} from RE to TC cells.

$$I_{GABA_A}(V, \{s_{Aj}\}) = g_{GABA_A}(V - V_{GABA_A}) \sum_{j=1}^{N} w_{RT}(i - j)s_{Aj}$$

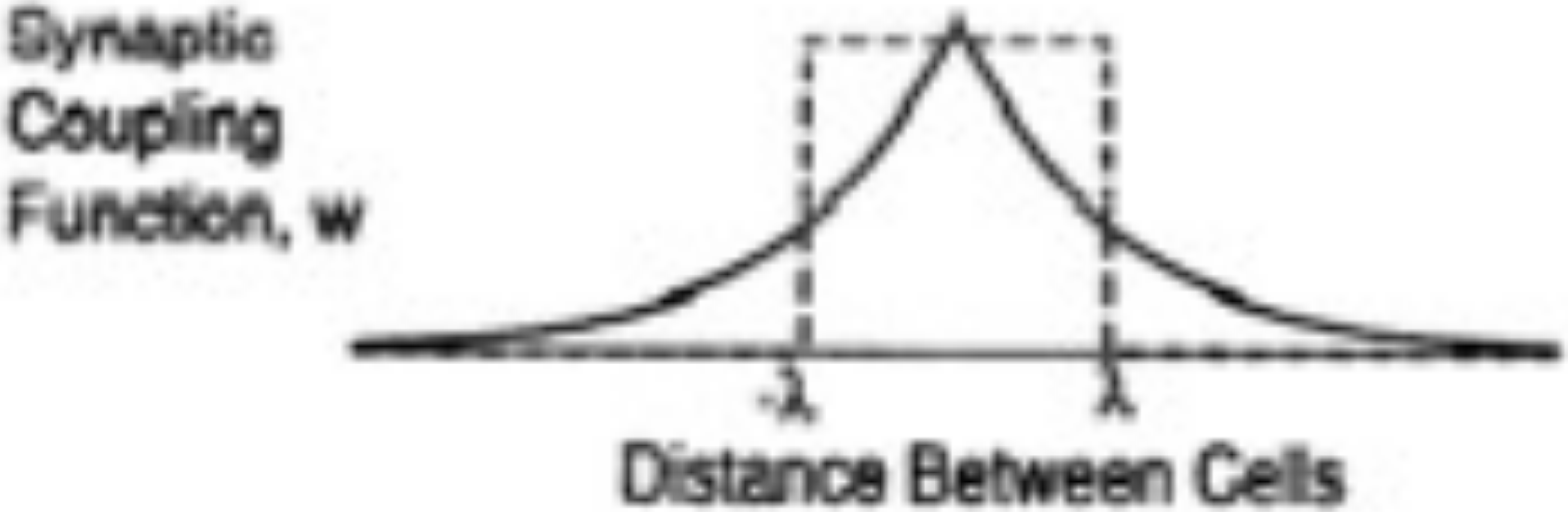
$GABA_B$ current I_{GABA_B} from RE to TC cells.

$$I_{GABA_B}(V, \{s_{Bj}\}) = g_{GABA_B}(V - V_K) \sum_{j=1}^{N} w_{RT}(i - j)s_{Bj}$$

$$\frac{dx_B}{dt} = k_{fx}S_\infty(V_{pre})(1 - x_B) - k_{rx}[1 - S_\infty(V_{pre})]x_B$$

$$\frac{ds_B}{dt} = k_{fB}x_B^4(1 - s_B) - k_{rB}s_B$$

Footprint



Initiation

- TC (excitatory cells) are only excited via Ih hyperpolarization activated current
- RE cells receive AMPA mediated excitatory currents from TC cells

Propagation- “Lurch”

- TC cells must be hyperpolarized for long enough to rebound
- They excite RE cells on the right of the propagating wave front