Stochastic memory: 
getting memory out of noise

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A. Stotland and M. Di Ventra, “Stochastic memory: getting memory out of noise”, to be submitted
Outline

- *Stochastic* memory elements
- The concept of stochastic resonance
- Example - TiO$_2$ memristor
- Theoretical predictions of the model
Stochastic memory elements

Definition:

\[ \{y(t)\}_\xi = \{g(x, u, t)\}_\xi u(t) \]

\[ \dot{x} = f(x, u, t) + H(x, u, t)\xi(t) \]

\[ \langle \xi_i(t) \rangle = 0, \quad \langle \xi_i(t)\xi_j(t') \rangle = k_{ij}(t, t') \]

\( H(x, u, t) \equiv 0 \Leftrightarrow \text{deterministic element} \)

<table>
<thead>
<tr>
<th>\textbf{u}(t)</th>
<th>\textbf{y}(t)</th>
<th>\textbf{system}</th>
</tr>
</thead>
<tbody>
<tr>
<td>current</td>
<td>voltage</td>
<td>memristive</td>
</tr>
<tr>
<td>charge</td>
<td>voltage</td>
<td>memcapacitive</td>
</tr>
<tr>
<td>current</td>
<td>flux</td>
<td>meminductive</td>
</tr>
</tbody>
</table>

Y. V. Pershin and M. Di Ventra, Advances in Physics, 60, 145 (2011)
Stochastic resonance

Example - Pt–TiO$_{2-x}$–Pt

\[ M(w) = \frac{w}{L} R_{\text{ON}} + \left(1 - \frac{w}{L}\right) R_{\text{OFF}} \]

\[ I(t) = \frac{V(t)}{M(w)} \]

\[ \frac{dw}{dt} = \frac{\mu_D R_{\text{ON}}}{L} I(t) + L \xi(t) \]

White Gaussian Noise:
\[ \langle \xi(t) \rangle = 0, \quad \langle \xi(t) \xi(t') \rangle = \Gamma \delta(t - t') \]

Results - Pt–TiO$_{2-x}$–Pt

Applied voltage: $V(t) = V_0 \sin \omega t$

Noise can be used to enhance memory effects!
Results - Pt–TiO$_{2-x}$–Pt

- Maximum memory effect enhancement is achieved for the maximum Signal-to-Noise Ratio
Theoretical predictions of the model

- Memory effects can be enhanced by tuning **frequency** and/or **noise**

- To see the memory effect enhancement experimentally in Pt–TiO$_{2-x}$–Pt device one can reduce the frequency and vary the external temperature.