Norbert Marwan, Niels Wessel, Jürgen Kurths

Complex Network Approach for Recurrence Analysis of Cardiovascular Oscillations
Dynamical System

- States represented in phase space
- Trajectory represents the system’s dynamics
- Recurrences
Recurrence Plot
Recurrence Plot
Recurrence Plot

- recurrence plot: symmetric and binary matrix
Recurrence Plot

- Transition detection
- Differentiate dynamics
- Finding time scales
- Synchronisation analysis
- etc.

- recurrence plot: symmetric and binary matrix
Complex Networks

- Successful applications in many fields
  - social networks
  - brain dynamics
  - power grids
  - metabolic networks etc.
Complex Networks
Complex Networks
Complex Networks

node

link

non-trivial topology

Montag, 3. März 2014
Complex Networks
Complex Networks

- link matrix (undirected, unweighted network):
  - binary
  - symmetric

\[
A_{i,j} = \begin{bmatrix}
0 & 1 & 0 & 0 & 1 \\
1 & 0 & 1 & 0 & 1 \\
1 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 1 \\
1 & 1 & 0 & 1 & 0
\end{bmatrix}
\]
Complex Networks

- link matrix (undirected, unweighted network):
  - binary
  - symmetric

\[ A_{i,j} = \begin{bmatrix}
0 & 1 & 0 & 0 & 1 \\
1 & 0 & 1 & 0 & 1 \\
0 & 1 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 1 \\
1 & 1 & 0 & 1 & 1
\end{bmatrix} \]

- link matrix: similar to recurrence plot

Montag, 3. März 2014
Complex Networks
Complex Networks

random network
Complex Networks

small-world network
Complex Networks

scale-free network
Complex Networks

scale-free network
Complex Networks
Complex Networks
Complex Networks

- degree centrality: importance of vertex for network
Complex Networks
Complex Networks
Complex Networks
Complex Networks

- clustering coefficient: clustering of nodes
Time Series Analysis using Complex Networks

- Link matrix = recurrence matrix of time series
- Nodes: states in phase space
- Links: local neighbours of states

Time Series Analysis using Complex Networks

- Link matrix = recurrence matrix of time series
- Nodes: states in phase space
- Links: local neighbours of states

Time Series Analysis using Complex Networks

- Complex network measures applied to recurrence plot
  - measures of complexity explaining dynamical properties complex systems

Time Series Analysis using Complex Networks
Time Series Analysis using Complex Networks

- clustering coefficient: regularity of dynamics
Early Detection of Preeclampsia in Pregnancy

- Life-threatening cramps for mother and fetus
- Under-supply of the fetus
- Growth retardation
Early Detection of Preeclampsia in Pregnancy

- Life-threatening cramps for mother and fetus
- Under-supply of the fetus
- Growth retardation

- positive predictive value appr. 20-30%
Early Detection of Preeclampsia in Pregnancy

- 20th week of gestation
- Systolic and diastolic blood pressure (S, D)
Early Detection of Preeclampsia in Pregnancy

- 20th week of gestation
- Systolic and diastolic blood pressure (S, D)
- Heart rate variability (H)

Malberg et al, Chaos 17, 015113 (2007)
Early Detection of Preeclampsia in Pregnancy

- 20th week of gestation
- Systolic and diastolic blood pressure (S, D)
- Heart rate variability (H)

Malberg et al, Chaos 17, 015113 (2007)
Early Detection of Preeclampsia in Pregnancy

Montag, 3. März 2014
Early Detection of Preeclampsia in Pregnancy

\[ \vec{x}(t) = \begin{pmatrix} H(t) \\ D(t + 1) \\ S(t + 2) \end{pmatrix} \]
Early Detection of Preeclampsia in Pregnancy
Early Detection of Preeclampsia in Pregnancy

Montag, 3. März 2014
Early Detection of Preeclampsia in Pregnancy
# Early Detection of Preeclampsia in Pregnancy

<table>
<thead>
<tr>
<th></th>
<th>Preeclampsia</th>
<th>Control</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>H (ms)</td>
<td>734.5 (±110.8)</td>
<td>760.5 (±111.7)</td>
<td>n.s.</td>
</tr>
<tr>
<td>S (mmHg)</td>
<td>123.0 (±15.4)</td>
<td>123.5 (±20.0)</td>
<td>n.s.</td>
</tr>
<tr>
<td>D (mmHg)</td>
<td>75.5 (±10.4)</td>
<td>66.6 (±13.9)</td>
<td>n.s.</td>
</tr>
<tr>
<td>recurrence rate</td>
<td>0.14 (±0.04)</td>
<td>0.16 (±0.05)</td>
<td>0.0024</td>
</tr>
<tr>
<td>laminarity</td>
<td>0.80 (±0.10)</td>
<td>0.83 (±0.08)</td>
<td>n.s.</td>
</tr>
<tr>
<td>clustering</td>
<td>0.60 (±0.03)</td>
<td>0.62 (±0.04)</td>
<td>0.0015</td>
</tr>
</tbody>
</table>
Early Detection of Preeclampsia in Pregnancy

<table>
<thead>
<tr>
<th></th>
<th>Preeclampsia</th>
<th>Control</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>H (ms)</td>
<td>734.5 (±110.8)</td>
<td>760.5 (±111.7)</td>
<td>n.s.</td>
</tr>
<tr>
<td>S (mmHg)</td>
<td>123.0 (±15.4)</td>
<td>123.5 (±20.0)</td>
<td>n.s.</td>
</tr>
<tr>
<td>D (mmHg)</td>
<td>75.5 (±10.4)</td>
<td>66.6 (±13.9)</td>
<td>n.s.</td>
</tr>
<tr>
<td>recurrence rate</td>
<td>0.14 (±0.04)</td>
<td>0.16 (±0.05)</td>
<td>0.0024</td>
</tr>
<tr>
<td>laminarity</td>
<td>0.80 (±0.10)</td>
<td>0.83 (±0.08)</td>
<td>n.s.</td>
</tr>
<tr>
<td>clustering</td>
<td>0.60 (±0.03)</td>
<td>0.62 (±0.04)</td>
<td>0.0015</td>
</tr>
</tbody>
</table>
# Early Detection of Preeclampsia in Pregnancy

<table>
<thead>
<tr>
<th></th>
<th>Preeclampsia</th>
<th>Control</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>H (ms)</td>
<td>734.5 (±110.8)</td>
<td>760.5 (±111.7)</td>
<td>n.s.</td>
</tr>
<tr>
<td>S (mmHg)</td>
<td>123.0 (±15.4)</td>
<td>123.5 (±20.0)</td>
<td>n.s.</td>
</tr>
<tr>
<td>D (mmHg)</td>
<td>75.5 (±10.4)</td>
<td>66.6 (±13.9)</td>
<td>n.s.</td>
</tr>
<tr>
<td>recurrence rate</td>
<td>0.14 (±0.04)</td>
<td>0.16 (±0.05)</td>
<td>0.0024</td>
</tr>
<tr>
<td>laminarity</td>
<td>0.80 (±0.10)</td>
<td>0.83 (±0.08)</td>
<td>n.s.</td>
</tr>
<tr>
<td>clustering</td>
<td>0.60 (±0.03)</td>
<td>0.62 (±0.04)</td>
<td>0.0015</td>
</tr>
</tbody>
</table>

Positive accuracy value: 60%  
Negative accuracy value: 80%
Conclusions

• Complex network analysis of time series
• Complementary insights
• Applicable to non-stationary and noisy data
• Preeclampsia: first promising results
Publications


