Statistical Characteristics of Human Activities

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“Statistical analysis of air traffic controllers’ eye movements” in USA & Europe Air Traffic Management R&D Seminars, August 2015.

A day back in 2009 with the story of “Human Dynamics”

Regular patterns in human dynamics can be characterized with heavy-tailed, power-law distributions instead of ever-belief Poisson-like distributions.

CORRESPONDENCE PATTERNS: Mechanisms and models of human dynamics

**Charles Robert Darwin** (1809 – 1882)
Sent: 7,591 Received: 6,530

**Albert Einstein** (1879 - 1955)
Sent: 14,500 Received: 16,200
There has been a surge of reports on human dynamics since 2006, which have uncovered regular patterns of human communications, mobility, and other interactive activities.

Human dynamics research has unmasked astonishing statistical characteristics such as scaling behaviors in human daily activities.

Heavy tailed human activities

- Correspondence
- Email
- Printing
- Webpage view
- Online movies rating
- Library loan
- SMS
- Phone calls
- Financial activities
Empirical results show there exist similarities between activities patterns among human beings, which are irrelevant to the context of the activities.

But, does scaling law exists in task-specific activities, such as the ones subjected to high pressure?
Scaling behaviors is one hallmark of complex systems, indicating that no characteristic scale dominates the dynamics of underlying process.

Human, as the most complex one, exhibits scaling phenomena at different layers, from cell activities and DNA behaviors to social activities...

We approach Fluctuation Scaling since we believe that human activities are subjected to stochastic perturbations, therefore exhibits fluctuations.

\[ \text{fluctuation} \approx \langle \text{average activities} \rangle^\alpha \]

Air Traffic Control is a Task-Specific Activities Subjected to High Pressure...
Why Air Traffic Controllers behaviors?

- Safety – Operational risk
- Capacity – Mental workload
- Efficiency – Environmental issues
- Optimization of airspace structure & procedures
- Understanding of human activities under pressure
- Applications to other complex systems

Most of information are acquired through vocal communication and visual systems.

Initial Test – 5 empirical datasets

Two real-time simulation datasets:
- (D1) Paris TMA
  - 22 sectors, 14 exercises, 2-week long
- (D2) ATCOSIM Dataset
  - 50 exercises, 59 hours

Three operational datasets:
- (D3) Atlanta ARTCC
  - 4 sectors, 8 samples
- (D4) Chicago ARTCC
  - 1-month long
- (D5) Chinese ACCs
  - 8 sectors, 26 samples
The inter-gap lengths

Three parts of the required time for a successful message transmission

- **P1**: Length of controller’s message;
- **P2**: Idle time;
- **P3**: Length of pilot’s message.

In average, it takes 11 seconds for the transmission!


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Distribution of inter-gap lengths
(Power law fitting)

Exponents are larger than others in human dynamics; The adaptive interest-driven model can explain the rapidly decayed heavy-tailed distribution here.
Testing the self-affinity of the communication activities
Detrended Fluctuation Analysis (DFA) on the five empirical datasets.

Controllers’ communications are long-range correlated.

Initial results indicate that high-pressure activities signed higher $\alpha$ exponents, and average communication activity and its $\sigma$ can be described by Taylor’s Power Law but any other Task Specific elements?

Dependent on Traffic?
Any Cognitive Processes that Influences?
Can Figure Out Airspace Complexity as an Index?
Taylor’s power law
(Nature, 1961)

\[ \text{fluctuation} = \text{const.} \times \text{average}^\alpha, \text{ where } \alpha \in [1/2, 1] \]

Used to characterize the relationship between the fluctuation in the activity of an element and the average activity.

Test with 2 Datasets

(D1) Paris TMA Simulation
- Records of a 2-weeks training at EEC in June 2010
- 100 participants
- 30 airspace sectors (10 en-route)
- 14 exercises x 90 minutes long/each
- 79847 communication events by controllers

(D2) Shanghai ACC Operations
- 15 days of data in March 2013 of all flights above FL60 whole China
- Records trajectories and A/G com.
- 20 en-route sectors
- 60,000 flights
- 200,000 communications events by controllers
Correlations between traffic and communication

Traffic activities and comm. activities (Paris TMA Data)
Results: Fluctuation scaling (D1 Datasets)

\[ \alpha = 0.54 \pm 0.01 \]

Results: Fluctuation scaling (with D2 Dataset)

\[ \alpha = 0.77 \pm 0.01 \]

STD of communication activities (in log)

Average of communication activities
Difference confirmed and suggests that human dynamics under pressure of more likely dominated by the exogenous force.

Traffic Dynamics as Cognitive Process?

How can we capture the dynamics of traffic in controller’s mind?

AF112 and CA982 will be at the same altitude in 2 mins.
UN007 has to speed up!!!
There’s severe weather at PIKAS.

The control sequence should be: CZ76, AF117, ...
Structure-based abstractions (Histone and Hansman, 2002, 2008)

Network dynamics approach

Construction of the network:
Nodes are the flights transverse the sector;
Links indicate the relationships between the two nodes:

\[ l_{ij} = \begin{cases} 
1, & d_{ij} \leq d_{tw} \\
0, & \text{otherwise} 
\end{cases} \]

\[ d_{ij} \]: time intervals between the communications related to flight i and j;
\[ d_{tw} \]: predefined time window.
Relationship between AF113ZL and BZ682ZR

The degree of the node denotes the number of neighbor flights. The more neighbors the flight has, the more important this flight is.

\[ I_{ij} = 0, w_{ij} = 0, \text{ if } d_{ij} \leq 5(s) \]
\[ I_{ij} = 1, w_{ij} = 1, \text{ if } 5(s) < d_{ij} < 125(s) \]
\[ I_{ij} = 1, w_{ij} = 2, \text{ otherwise} \]

The temporal networks

\[ t = t_0 + \Delta t \quad t = t_0 + 2\Delta t \quad t = t_0 + 3\Delta t \quad \text{Aggregated} \]
Results: Temporal networks

Degree distribution in the temporal networks
- Most of flights have degree of two, rather than six
- Indicating the dynamical grouping behavior of the controller.

A Temporal Network of Events
Weighting

Degree distribution: \( d_{tw} = 60(s), w_{\min} = 1 \)
Degree distribution: $d_{tw} = 60(s), w_{min} = 2$

Degree distribution: $d_{tw} = 60(s), w_{min} = 3$
Degree distribution: \( d_{tw} = 60(s), w_{\min} = 4 \)

Degree distribution: \( d_{tw} = 60(s), w_{\min} = 5 \)
Spatial behavior

The degree distributions have quite similar shapes across all the sectors;
Most flights have degree of six;
With smaller $d_{\text{min}}$ and $w_{\text{min}}$, most of data can be described as a Poisson distribution or Normal distribution.
When $w_{\text{min}}$ exceeds 4, the change on degree distribution suggests a transformation of the network.
So, Exogenous force could be cognitive processes. When the weight of the network increases, i.e. grouping of reasoning increases, the distribution changes from Poisson to Power Law.

The end of two decades of investigation into “Human Workload as a Function of Traffic.”

Information-seeking behavior: The analysis of eye movements

Traffic Dynamics as Visual Activities?
Ilya Yefimovich Repin, An Unexpected Visitor, 1884
Ilya Yefimovich Repin, An Unexpected Visitor, 1884
Goal-attenuated eye movement

Information-seeking behaviors

Three lines of investigation on information-seeking reviewed in Gottlieb et al. 2013

- Machine learning fields: Information-seeking obeys the imperative to reduce uncertainty and can be extrinsically or intrinsically motivated
- Natural behaviors: Task-directed searches for information through the prism of eye movements
- Psychology and neuroscience: Curiosity and autonomous exploration
Which parts of the airspace are most likely to be viewed by the controllers?

How do controllers scan the radar screen?

Comparisons on N. of AOIs and fixation duration

<table>
<thead>
<tr>
<th>Level</th>
<th>Mean number of Area of Interest (AOI)</th>
<th>Mean Fixation Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level-Two</td>
<td>1200</td>
<td>3.5</td>
</tr>
<tr>
<td>Level-Three</td>
<td>1500</td>
<td>4.0</td>
</tr>
<tr>
<td>Level-Four</td>
<td>1800</td>
<td>4.5</td>
</tr>
<tr>
<td>Level-Five</td>
<td>2100</td>
<td>5.0</td>
</tr>
<tr>
<td>Novice</td>
<td>2400</td>
<td>5.5</td>
</tr>
</tbody>
</table>
Comparisons on N. of AOIs and fixation duration

![Graph showing comparisons on N. of AOIs and fixation duration.](image)

- **Cat. I**: Mean number of Area of Interest (AOI) number: M=126, Smallest #. AO
- **Cat. II**: Mean number of Area of Interest (AOI) number: M=1.66, Longest fixation
- **Cat. III**: Mean number of Area of Interest (AOI) number: Average of AOIs, 1521

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Comparisons on N. of AOIs and fixation duration

Comparisons on N. of AOIs and fixation duration

Large #. of AOIs Minimum of fixation durations
Comparisons on the std.

Smallest variation in Level-Two controllers

Largest variation in Novices

Heat map of fixation: Level-Two
Heat map of fixation: Level-Three

Heat map of fixation: Level-Four
Summary on information-seeking behavior

Contributions

Working experience have significant effects on eye movements, indicating different information seeking mechanisms among qualified controllers.

Limitations

Scan patterns should be further analyzed
To investigate the effects of traffic conflict and abnormal events on scan patterns
Conclusions on ATCO communications

Can be characterized by Taylor's power-law
High pressure results in large scaling exponent due to exogenous forces
Detection of fluctuation scaling captures adaptive phenomena of activities, and
Statistics of Communications can figure out complexity of airspace: new index

Thank you for your attention