Enhancing Professional Social Network visualization by Lean-inspired Measures on the individual

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***Abstract*—In this paper we'll consider social networks extracted from event logs and explain how to improve the efficacy of their visualization by inserting additional measures, related to the single individual, that can be calculated basing always on the event log. These measures, which we'll show to have a business meaning, are Lean (manufacturing)-inspired and aim to give a clear information about bottlenecks or critical points inside an organization. The assessment of these measures is mainly done on the BPI Challenge 2012 event log. We'll show also how to further improve their efficacy by doing an initial filtering on the event log.**

I. Introduction

Business Process mining [1], [2] is a relatively young sector of Business Intelligence which aims to get valuable informations about the processes of an organization. Some of these informations regard social structure of the organization [3]: business-related metrics between individuals (for example, Handover of Work (HoW), Working Together (WT) and Similar Activities (SA)) are calculated in order to be able:

1) To understand related groups of people inside the organization (WT lets to find people who work for the same cases, and SA lets to find the ones which share the same activities). This can be done using a clustering algorithm [4], [5], [6], which finds groups of individuals "similar" in the given metric.
2) To visualize the social network structure of the organization, in order to be able to fully understand relations between individuals and their importance. This also lets to understand if there are isolate workers, and if there are workers that overlaps between several communities (being gate-keepers). This can be done using a graph visualization algorithm [7], [8], [9], that does a placement of the nodes (i.e. the individuals) on the screen in order to get a clear view of the social network graph.

Most graph visualization techniques, however, regard only the placement of the node and don't treat other important things in visualization; these include the nodes colours and dimensions. Dimension can be assigned by judging the node centrality in the social network [10], [11]; the centrality of an individual is a function of its in and out edges. Color [12], [13] can be assigned basing always on centrality, or by basing on additional informations (like the gender of the individual; i.e. you can choose BLUE for males and PINK for females).

These additional informations are important because can't be inferred by the given social network relations, in contrast to centrality, and have to be obtained separately. Being interested in business analysis, it can be a good idea to use other informations that can be obtained from the event log, and which are related to the single individual (i.e., individual measures).

Some important ideas in this direction can be read in Lean manufacturing techniques [14], [15], [16] which aim to understand the value of organizational processes and to offer a way to improve them, discovering which things are really value and which ones are not. These ideas apply to processes, but we'll try to extend them to individuals, as the behaviour of a single process is the sum of performance of behaviours of single individuals.

II. Background

Event logs are collections of events happening inside an organization. For our purposes, we'll consider an event as a sextuple

$$e = (p, c, i, a, st, ct)$$

Where p and c are respectively the process and the case (process instance) the event belong to, i is the individual which does it, a is the action done, and st,ct are respectively the start time and the completion time of the event. Is is indeed important to notice that these events have a lifespan (i.e. they start and they finish), and so are not instantaneous events, and this can lead to important differences in business intelligence analysis (see [17]). We consider lifespan information essential for our purposes, as we'll measure performances and workloads. The following notation will help for our purposes. We define

$$\text{LIFESPAN}(e) = \rho_{ct}(e) - \rho_{st}(e)$$

as lifespan of the single event (where ρ_{ct} and ρ_{st} are respectively functions that return the completion and the start time of the event), and

$$\text{LIFESPAN}(C) = \max_{e \in L, \rho_c(e)=C} \rho_{ct}(e) - \min_{e \in L, \rho_c(e)=C} \rho_{st}(e)$$

the lifespan of a case C (where ρ_c is a function that associates to each event its case).

We resume in Table I some metrics between individuals, referring to the work of Van der Aalst [3]. Indeed, while some metrics don't require any change when considering events with lifespan ("interval" events, [17]), Handover of Work requires little work.

TABLE I
SOME METRICS BETWEEN INDIVIDUALS, THAT CAN BE CALCULATED ON EVENT LOGS.

WORKING TOGETHER
$\text{NC}(i_1) = \#\{C, \exists e \in L, \rho_i(e) = i_1, \rho_c(e) = C\}$ $\text{NC}(i_1, i_2) = \#\{C, \exists e, e' \in L, \rho_i(e) = i_1, \rho_i(e') = i_2, \rho_c(e) = \rho_c(e') = C\}$
$\text{WT}(\mathbf{i_1}, \mathbf{i_2}) = \mathbf{NC(i_1, i_2)/NC(i_1)}$
SIMILAR ACTIVITIES
$\text{IA}(i_1, a_1) = \#\{e \in L, \rho_i(e) = i_1, \rho_a(e) = a_1\}/\#\{e \in L, \rho_i(e) = i_1\}$
$\text{SA}(\mathbf{i_1}, \mathbf{i_2}) = \mathbf{1} - \sum_{\mathbf{a_1}} (\mathbf{IA(i_1, a_1)} \cdot \lvert\mathbf{IA(i_1, a_1)} - \mathbf{IA(i_2, a_1)}\rvert)$
HANDOVER OF WORK
$\text{NE}(e) = \arg\min\{\rho_{st}(e') \lvert \rho_{st}(e') > \rho_{ct}(e), \rho_c(e) = \rho_c(e')\}$
$\text{HW}(\mathbf{i_1}, \mathbf{i_2}) = \#\{\mathbf{e} \in \mathbf{L}, \rho_\mathbf{i}(\mathbf{e}) = \mathbf{i_1}, \rho_\mathbf{i}(\text{NE}(\mathbf{e})) = \mathbf{i_2}\}/ \#\{\mathbf{e} \in \mathbf{L}, \rho_\mathbf{i}(\mathbf{e}) = \mathbf{i_1}\}$

Working Together metric between two individuals i_1 and i_2 measures how many cases they work in common in comparison with the overall number of cases worked by i_1. Similar Activities measures how much similar the activities of two individuals are: [3] provides several definitions, and in Table I we are considering the Minkowski distance. We are considering directed metrics: so $\text{WT}(i_1, i_2)$ can be different from $\text{WT}(i_2, i_1)$, and $\text{SA}(i_1, i_2)$ can be different from $\text{SA}(i_2, i_1)$.

Handover of Work can be defined basing on a next-event function, which may be undefined if the event is the last (or the only one) of its case. The definition of the next event takes in account the fact we are considering "interval" events, so they start and they finish in different times.

III. MEASURES ON THE INDIVIDUAL

In this section we'll introduce several measures on the individual, and show how to calculate them basing on event logs. The eventual formulas to apply have been written in Table II.

Performance The word "performance" can have various meanings. For example, performance of a house seller may be measured on how much money he can get selling houses, or performance of a CEO may be seen by the company's profits. In our case, performance is time-related. Organizations may have several people doing the same activities, and have the need to measure their performance on non-financial terms (as [14] and [18] points out, non-financial performance has an impact on financial performance). As example, a telephone company may prefer a technician which resolves a particular problem in 2 hours, instead of one that finishes the same issues in 3 hours.

One option is about judging the average completion time of the activities of the given worker, in comparison to the average completion times of the same activities. Indeed, the lower is the average, the better can the performance be judged. This is the approach we have followed in judging it.

However, as the Six Sigma approach points out ([19]), average completion time may not be complete to judge performance: the suggestion is about considering avg+6·std (average plus six times standard deviation) as performance measure, as predictability plays a large part in having consistent processes inside an organization. Unfortunately, the idea of considering avg + 6 · std of the single worker in comparison to avg + 6 · std of all workers in the organization is biased from the fact std of general completion times is usually higher than std of the single worker (because the level of performance of workers can be different).

Workload and Interrupted Organizations might be interested in seeing which workers has higher amounts of work to do. This is interesting as an overloaded worker may offer lower performances in doing its activities. Overload can be of two different types

1) Instantaneous overload: it may happen that the worker has an exceptional high amount of things to do in a given moment.
2) Constant overload: a worker may have always many things to do.

The first option is generally the most dangerous one as it may result in a severe delay of completion times. The second is also dangerous because stressed workers generally offer lower performances ([20]). We introduce two measures, one (*Workload*) that has high scores when the worker has an instantaneous overload, the other (*Interrupted*) that shows high scores when there is constant overload. These measures are Lean manufacturing inspired [14],[15] as the correct balancing of loads is key to improving the organization behaviour.

Workload for a single event e may be defined as the number of different activities done by the worker $\rho_i(e)$ in e's lifespan. Then, workload of the single worker w is defined as the maximum workload of events done by the given worker (events e where $\rho_i(e) = w$). We are taking, indeed, the maximum number of activities done contemporaneously.

Interrupted measure, for worker w, is instead taken as the sum of the workloads of the events e where $\rho_i(e) = w$. It is worthy to note that high values here means the worker has a constant overload.

For both metrics, we should have a negative relation with performance: workers with high Workload or high Interrupted measure aren't, indeed, in the best position to do their work efficiently.

Work in Process

Work in Process is a Lean measure [14] that takes in account how many instances of the same process are opened in the same time. Having many instances opened, indeed, may be related to high production times (as the people assigned to the same process have to work various instances) and possibly to stockage costs. As the good behaviour of a process is connected to the good behaviour of people assigned to it, we can introduce a Work in Process measure for the individual w which represent the maximum number of instances of the same process which are active during the cases worked by w.

This is a possible sign of overload for the worker as having many instances opened contemporaneously may be a severe stress for him. High values of WIP should be, generally, corresponding to high values of the Workload and Interrupted measures. Also, high values of WIP should be corresponding to lower performances (as the worker is "split" between different instances).

Criticality

Criticality is a measure related to the importance of the activities that the worker does for the organization. Indeed, he may be the only one that can perform some activities, so if something happens to him (for example, he dies) the organization may get in severe troubles. We can define it as the maximum, over all possible activities, of the percentage of the activity which is effectively done by the worker.

High criticality should be related with high workload and interrupted metric, as the worker may be the only one that can do some activities and, so, be stressed with an high number of different instances. For the same reason, it should be related to lower performance measures.

Average Resource Stead

We derive ARS (*Average Resource Stead*) from the Takt Time (which is a Lean measure [21], [22] that takes in account the "rhythm of production", so the completion time, required by the customer, for the instances of the given process). Indeed, we can define ACI (*Average Contemporaneously Instances*) for a process p as the ratio of the average completion time of instances of p and the Takt Time of p; it is a measure of the average number of instances that an organization need to keep open contemporaneously. Then, ARS for a worker w is simply the weighted average of ACI, based on the number of events w does along the given process.

This measure offer a way to judge employability of people in the organization, basing on the ARS-measured utility of similar workers inside an organization, and should as a result be consistent along groups of people working for the same cases. High values of ARS can be generally related to high values of Criticality, as the need of keeping many instances of the same process opened contemporaneously may mean too few workers are assigned to the given process.

TABLE II
SOME MEASURES ON THE INDIVIDUAL, THAT CAN BE CALCULATED ON EVENT LOGS.

PERFORMANCE
$\text{IA}(i_1, a_1) = \#\{\, e \in L, \rho_i(e) = i_1, \rho_a(e) = a_1 \,\} / \#\{\, e \in L, \rho_i(e) = i_1 \,\}$
$\text{PERF}(a_1) = \text{avg}_{e \in L, \rho_a(e) = a_1} \text{LIFESPAN}(e)$
$\text{PERF}(i_1, a_1) = \text{avg}_{e \in L, \rho_i(e) = i_1, \rho_a(e) = a_1} \text{LIFESPAN}(e)$
$\text{PERF}(\mathbf{i_1}) = \sum_{\mathbf{a_1}} \text{IA}(\mathbf{i_1}, \mathbf{a_1}) \cdot (\text{PERF}(\mathbf{a_1}) / \text{PERF}(\mathbf{i_1}, \mathbf{a_1}))$
WORKLOAD and INTERRUPTED
$\text{WLOAD}(e) = \#\{\, e' \in L,\ \rho_i(e') = \rho_i(e), \rho_{st}(e) \leq \rho_{st}(e') < \rho_{ct}(e) \,\}$
$\text{WLOAD}(\mathbf{i_1}) = \max_{\mathbf{e} \in \mathbf{L}, \rho_\mathbf{i}(\mathbf{e}) = \mathbf{i_1}} \text{WLOAD}(\mathbf{e})$
$\text{INTERR}(\mathbf{i_1}) = \sum_{\mathbf{e} \in \mathbf{L}, \rho_\mathbf{i}(\mathbf{e}) = \mathbf{i_1}} \text{WLOAD}(\mathbf{e})$
WORK IN PROCESS
$\text{WIP}(e) = \#_{\text{Distinct}} \{\, \rho_c(e') \mid e' \in L, \rho_p(e') = \rho_p(e), \rho_{st}(e) \leq \rho_{st}(e') < \rho_{ct}(e) \,\}$
$\text{WIP}(c_1) = \max_{e \in L, \rho_c(e) = c_1} \text{WIP}(e)$
$\text{WIP}(\mathbf{i_1}) = \max_{\mathbf{e} \in \mathbf{L}, \rho_\mathbf{i}(\mathbf{e}) = \mathbf{i_1}} \text{WIP}(\rho_\mathbf{c}(\mathbf{e}))$
CRITICALITY
$\text{CR}(i_1, a_1) = \#\{\, e \in L, \rho_i(e) = i_1, \rho_a(e) = a_1 \,\} / \#\{\, e \in L, \rho_a(e) = a_1 \,\}$
$\text{CR}(\mathbf{i_1}) = \max_{\mathbf{a_1}} \text{CR}(\mathbf{i_1}, \mathbf{a_1})$
ARS
$\text{IP}(i_1, p_1) = \#\{\, e \in L, \rho_i(e) = i_1, \rho_p(e) = p_1 \,\} / \#\{\, e \in L, \rho_i(e) = i_1 \,\}$
$\text{TAKT}(p_1) = \left(\max_{e \in L} \rho_{ct}(e) - \min_{e \in L} \rho_{st}(e)\right) / \#\{\, \rho_c(e) \in L, \rho_p(e) = p_1 \,\}$
$\text{ACI}(p_1) = \left(\text{avg}_{c \in p_1} \text{LIFESPAN}(c)\right) / \text{TAKT}(p_1)$
$\text{ARS}(\mathbf{i_1}) = \sum_{\mathbf{p_1}} \text{IP}(\mathbf{i_1}, \mathbf{p_1}) \cdot \text{ACI}(\mathbf{p_1})$

IV. VISUALIZATION OF THE MEASURES ON THE INDIVIDUAL

We have explained in the previous section how to calculate several metrics on the individual, which we have showed to have a precise business meaning. But how to view these metrics on the social network graph? We think that a good idea is about viewing them on the nodes' colour, associating red (a hot colour) when the measure is high and blue (a cold colour) when the measure is low. A possible method is the following, which takes in account all individuals in the organization. Calling MEDIAN the statistical median of the considered measure, and MAX the maximum value assumed by the measure, we can assign an RGB colour $\text{COLOUR}(i_1)$ to the individual in the following way:

If $\text{MEASURE}(i_1) < \text{MEDIAN}$ define

$$\text{CLEAR}(i_1) = k \cdot \left(1 - \frac{\text{MEDIAN} - \text{MEASURE}(i_1)}{\text{MEDIAN}}\right)$$

and then

$$\text{COLOUR}(\mathbf{i_1}) = \#\ (\text{CLEAR}(\mathbf{i_1}))\ (\text{CLEAR}(\mathbf{i_1}))\ \mathbf{FF}$$

where k is a parameter that we can call *clearness parameter* and defines how much clear can the colour get (if the individual is just below the median). We want, indeed, the colour to get more blue if the individual has a low score in the measure considered, and less blue if he is near to the median.

If $\text{MEASURE}(i_1) \geq \text{MEDIAN}$ define

$$\text{CLEAR}(i_1) = k \cdot \left(1 - \frac{\text{MEASURE}(i_1) - \text{MEDIAN}}{\text{MAX} - \text{MEDIAN}}\right)$$

and then

$$\text{COLOUR}(\mathbf{i_1}) = \#\ \mathbf{FF}\ (\text{CLEAR}(\mathbf{i_1}))\ (\text{CLEAR}(\mathbf{i_1}))$$

where k is a parameter that we can call *clearness parameter* and defines how much clear can the colour get (if the individual is just above the median). We want, indeed, the colour to get more red if the individual has a high score in the measure considered, and less red if he is near to the median.

We think that the previous ideas are good as taking the median as reference is important to avoid being biased by outliers in giving colours. In this way, half of the individuals will get a (possibly slight) blue colour, and half a (possibly slight) red colour. Taking $k = FF$ there is a smooth transition, while possibly losing efficacy of the visualization. Nevertheless, a lower value of clearness ($k = C8$) is advised to let colours being clearly distinguishable just above or just below the median.

V. Filtering by Lead Time

We'll describe here a method to improve the business significance of the previously introduced measures. This can be done *filtering* the event log, i.e. taking only process instances which are really interesting in order to understand criticalities inside the organization. The filter we consider is based on *Lead Time*, which is a Lean measure [23] that takes in account completion times; it keeps only instances which completion time is above a certain threshold.

The threshold can be expressed as $\text{avg} + k \cdot \text{std}$, where avg is the average completion time, std is the standard deviation of completion times and k is a real number that determine which instances are being keeped. If we take $k = 0$, we take all instances whose completion time is above the average; if we take $k = 6$, only a very small number of instances (if there are any) will be keeped.

Keeping only a small number of instances, what we should see is that measures like Workload, Interrupted and WIP are related more negatively with performance, given higher than usual completion times are probably caused by an exceptional high stress of the organizational processes.

VI. Assessment of the measures

We'll assess the Performance, Workload, Interrupted, WIP and Criticity measures on the BPI Challenge 2012 event log [24]. The challenge asked participants to focus on particular BPI (Business Process Intelligence) aspects of a real-life event log, using whatever technique (control-flow, social network, performance, predictive models). The considered event log contains instances of a single process, where various people and activities are involved, and is particularly significative because many activities aren't instantaneous but instead have a start and a completion time, and this lets us to deploy, on this freely-available log[1], the described measures. We'll start considering the unfiltered event log, containing all the events, and after that we'll consider the measures on the Lead time filtered log (choosing $k = 1$, so a good number of instances are discarded).

The Average Resource Stead (ARS measure will instead be assessed on a private event log, that collects events related to many different organizational processes. We couldn't use, with ARS, the BPI Challenge 2012 event log because it contains only a process, and all workers get the same ARS value. The private log, in turn, couldn't be used to assess Performance, Workload, Interrupted and WIP measures as it contains only instantaneous events.

We start our assessment with considering temporal consistency of the considered measures. We wanted to see if the values of the measures "splitting" the event log in two comparable periods are similar. This because it should be plausible that overloaded workers in one period are overloaded also in the other. BPI Challenge 2012 event log contains events from 01/10/2011 to 14/03/2012 and a good "turn point", that halves the log in two equal temporal periods, is 21/12/2011. So we are considering the following two periods:

- Period 1 (from 01/10/2011 to 21/12/2011)
- Period 2 (from 22/12/2011 to 14/03/2012)

The chosen way to judge the similarity of the measures in the two periods is the linear (Pearson) correlation. We think this instrument is suitable because we are considering the same measure in two periods. Outliers were removed from the measures[2], because Pearson correlation is very sensible to outliers.

TABLE III
Correlation of measures in two different comparable periods. We see always a good temporal consistency of the measures

Measure	Correlation
Performance	0.3201
Workload	0.3500
Work in Process	0.2001
Interrupted	**0.8005**
Criticality	**0.5647**
ARS	0.2386

In Table III we see that Criticality and Interrupted metrics have very good temporal consistency, as the correlation is very high. This because a critical worker in one period has good chance to be critical, in the sense defined for Criticality, also in the second; Interrupted is good as it takes in consideration the sum of interruptions and, then, is more consistent than measures that takes in account the maximum instantaneous overload. However, Workload, Work in Process and Performance shows also good temporal consistency. Also ARS, measured on the private event log, is consistent.

[1]The log can be found on the website http://www.win.tue.nl/bpi/2012/challenge

[2]Removing from the calculus individuals that, even in only one of the two periods, were above $\text{avg} + \text{std}$ or below $\text{avg} - \text{std}$.

Now we want to test relationships between (different) measures. This will be useful to "legitimate" a measure's business significance by observing how it relates with the other measures, answering to questions like "It is true that high workloads are associated with low performances?". We think that the Pearson correlation is always a suitable instrument for doing that[3]: results of the measures' correlation in the unfiltered BPI Challenge 2012 log are shown in Table IV.

TABLE IV
CORRELATIONS BETWEEN DIFFERENT MEASURES IN THE BPI CHALLENGE 2012 UNFILTERED LOG.

	PER	WL	INT	WIP	CRI
Performance		0.0479	**-0.2054**	-0.1259	**-0.2169**
Workload	0.0479		**0.6907**	**0.2989**	0.1120
Interrupted	**-0.2054**	**0.6907**		**0.4983**	**0.4224**
WIP	-0.1259	**0.2089**	**0.4983**		**0.3868**
Criticality	**-0.2169**	0.1120	**0.4224**	**0.3868**	

We see that:

- Performance is negatively correlated with the Interrupted, WIP and Criticality measures: overloaded workers offer lower performances than their mates.
- Workload, Interrupted and WIP measures are strongly interconnected, indicating that they are all a measure of individual's amount of work inside an organization.
- Criticality is negatively correlated with performance and has a good connection with Interrupted and Work in Process measures. This because a worker that hasn't an adequate number of counterparts inside an organization is often overloaded, and so offers poor performances.

We now apply a filtering based on Lead Time, with $k = 1$, keeping only instances whose duration exceeds avg + std. We expect the relationships between measures to become even more meaningful, because we are restricting to the instances that probably were more problematic for the organization.

TABLE V
CORRELATIONS BETWEEN DIFFERENT MEASURES IN THE BPI CHALLENGE 2012 EVENT LOG, FILTERED BY LEAD TIME ($k = 1$). WE SEE THAT THE CORRELATIONS BECOME EVEN MORE MEANINGFUL.

	PER	WL	INT	WIP	CRI
Performance		**-0.2981**	**-0.3195**	**-0.2504**	-0.1104
Workload	**-0.2981**		**0.7269**	**0.3617**	**0.3569**
Interrupted	**-0.3195**	**0.7269**		**0.5337**	0.1633
WIP	**-0.2504**	**0.3617**	**0.5337**		-0.1722
Criticality	-0.1104	**0.3569**	0.1633	-0.1722	

We see, in Table V, that:

- As expected, Workload, Interrupted and WIP are even more strongly interconnected, and more negatively correlated with performance.
- Criticality measure's correlation values have got worse. This because, in the considered event log (BPI Challenge 2012), Lead Time keeped instances excessive duration was not "due" to critical workers, but to other reasons (like great temporary amount of work).

[3]Removing from the calculus individuals that, even in only one of the two periods, were above avg + std or below avg − std.

The assessment of ARS has been done using a private log. While we have seen a good temporal consistency ($\mathbf{0.2386}$), reported in III, we couldn't compare it to measures like Performance, Workload, Interrupted and WIP as our private log contains only instantaneous events. So, the assessment followed a slightly different route:

- It was compared to the Criticality metric, calculated on the private log, reporting a correlation value of $\mathbf{0.2872}$. So there is a strong connection between ARS (which we recall measures the utility of the given professional for the organization) and Criticality of the worker.
- As we expected similar ARS inside groups of people working together, we compared ARS's standard deviation on all workers to the weighted[4] average of standard deviations inside groups of people that are grouped together by the Multilevel [4] clustering algorithm[5] basing on the Working Together metric [3]. The general standard deviation is $\mathbf{0.1703}$, while the average of standard deviations inside groups is $\mathbf{0.0291}$, according to what we expected.

VII. CONCLUSIONS

In this paper we have introduced several measures on the individual, explaining their business meaning and how to show them on the social network graph. We think that they can be useful to identify bottlenecks inside organizations. However, we must remark that these measures should be a start point, not an end point, for investigating the organization. Instances with high completion times should be investigated:

- Considering single activities which compose the instance, and workers assigned to them. Badly assigned tasks can prevent the organization to reach its goals.
- Taking in account the number of contemporaneous instances, which may happen to be exceptionally high in a period, damaging many instances without fault from workers.
- Considering the fact there may be instances whose importance is greater, so they get priority from the organization.

Indeed, many times a high completion time is due more to non-optimal specification of processes, or lack of workforce, rather than single workers' fault. So each conclusion must be carefully investigated, not only with Social Network Graph visualization but with other BPI tools. ProM [1] is a Process Mining tools enabling organizations to do several business process analysis (like discovering control-flow, calculating performances, using predictive models), that surely enrich an organization's insight on its processes.

VIII. ACKNOWLEDGEMENTS

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[4]Weighted by number of individuals.

[5]Which we believe to be a very good clustering method.

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