Lecture Notes in Electrical Engineering 130

Sio-Iong Ao
Len Gelman
*Editors*

# Electrical Engineering and Intelligent Systems

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Sio-Iong Ao • Len Gelman
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# Electrical Engineering and Intelligent Systems

Springer

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# Preface

A large international conference in electrical engineering and intelligent systems was held in London, UK, 6–8 July, 2011, under the World Congress on Engineering (WCE 2011). The WCE 2011 was organized by the International Association of Engineers (IAENG); the Congress details are available at: http://www.iaeng.org/WCE2011. IAENG is a non-profit international association for engineers and computer scientists, which was founded originally in 1968. The World Congress on engineering serves as good platforms for the engineering community to meet with each other and exchange ideas. The conferences have also struck a balance between theoretical and application development. The conference committees have been formed with over 200 members who are mainly research center heads, faculty deans, department heads, professors, and research scientists from over 30 countries. The conferences are truly international meetings with a high level of participation from many countries. The response to the Congress has been excellent. There have been more than 1,300 manuscript submissions for the WCE 2011. All submitted papers have gone through the peer review process, and the overall acceptance rate is 56.93%.

This volume contains 33 revised and extended research articles written by prominent researchers participating in the conference. Topics covered include computational intelligence, control engineering, network management, wireless networks, signal processing, internet computing, high performance computing, and industrial applications. The book offers the state of the art of tremendous advances in electrical engineering and intelligent systems and also serves as an excellent reference work for researchers and graduate students working on electrical engineering and intelligent systems.

Hong Kong, China — Sio-Iong Ao
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# Chapter 1
# Partial Exploration of State Spaces and Hypothesis Test for Unsuccessful Search

**Eleazar Jimenez Serrano**

## 1 Introduction

Validating the correctness of systems by generating the corresponding state space (SSp) is a common method limited by the possible exponential growth of its size, known as the SSp explosion problem. Probabilistic methods focus on analyzing just a fraction of the SSp by means of partial exploration, but the probability of omitting states is greater than zero, sometimes incorrect evaluations are bound to happen and conclusiveness is not achievable all the time.

Our research is to determine the existence of certain states without having to explore the entire SSp. This is done with a reachability analysis, by using a partial exploration algorithm.

The lack of conclusiveness in the analysis upon unsuccessful search is confronted here. We present how to treat the results with a statistical hypothesis test and decide with a level of confidence if certain state exists or not.

In the confines of reachability analysis in SSp generated from Petri net (PN) systems, there is a large list of works doing partial exploration [1, 5, 6, 11]. Although good results exist for some specific cases, others lack conclusiveness due to unsuccessful search [7, 8, 10].

The output of any partial exploration can be seen as a probabilistic sample. Upon unsuccessful search, a hypothesis test can be conducted for completeness using the sample. In general, random walk is used in the partial exploration algorithm, but random walk cannot be used as a sampling method because the probability that a given state is visited is far from being uniform [13]. Therefore, the sample is biased and any posterior hypothesis test will be incorrect.

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In this chapter first we show how to obtain a sample during the partial exploration of the SSp which is utilizable in any posterior hypothesis test, and second we explain how to give conclusiveness to the reachability analysis in the case of unsuccessful search by means of a hypothesis test.

This chapter presents a partial exploration algorithm guided by a quota sampling. It is basically a table of quotas to fill in during the exploration. The sampling method is neither totally unbiased nor valid variance estimate, but it goes in the direction toward obtaining a representative sample. Then, we show a proper treatment to the sample by means of a hypothesis test [10] to provide conclusiveness to the analysis.

## 2 Petri Nets and State Spaces

One analysis strategy for the state space (SSp) is exploration. The exploration can be complete and partial. A major difficulty in the partial exploration is to conduct a random search with proper length and simultaneously traversing it all.

To verify that a random sample of the SSp has been obtained from the corresponding exploration, we need the probability distribution of the variable $Y$, a metric of every state in the set $\Psi$ of the SSp. Since it is difficult if not impossible to know in advance the distribution of $Y$, by looking at a variable $X$, same metric of every state of the easily known superset $\Omega$ of the SSp, some parameters of $Y$ can be estimated.

To explain this, a model of system behavior like Petri nets will be used to graphically identify the superset $\Omega$ of the SSp. This section will introduce briefly the necessary theoretical concepts required to continue.

### 2.1 Petri Nets

A Petri net is a tuple ($P$, $T$, $A$, $B$, $Q$), where $P$ is a finite nonempty set of $i$ places, $T$ a finite nonempty set of $j$ transitions, $A$ the set of directed arcs connecting places to transitions, $B$ the set of directed arcs connecting transitions to places, and $Q$ is a capacity function for the places mapping $P \to \boldsymbol{N}$.

A Petri net is mathematically represented with the pre- and post-incident matrices $\vec{A}$ and $\vec{B}$, respectively, having both $i$ rows and $j$ columns, with values of $[A(p_i, t_j)]$ and $[B(p_i, t_j)]$, respectively.

The way to describe a state of the system is by putting tokens in the corresponding places. Tokens are black dots that exist only in the places. The function $m$ called marking maps $P \to \boldsymbol{N}$, and $m_0$ is the initial marking. A PN with initial marking is called a PN system. We say that a place $p$ is marked when $m(p) > 0$. A marking $m$ is represented with a vector $\vec{m} \in \boldsymbol{N}^i$.

The finite set of all possible markings (i.e., the reachability space) of a PN system is denoted by $\Psi(m_0)$, and $r_{m_0}$ denotes the number of elements in the set $\Psi(m_0)$.

The number of states generated from a PN system depends on the input and output arcs, the initial marking, and the way how the occurrence of transitions is specified. Occurrence of single transition is carried out for complete exploration of the SSp of a PN system. Occurrence of solely concurrent transitions could lead to incomplete exploration of the SSp.

In the general case, the only way to know all the markings that could result from one initial marking $m_0$ is throughout complete exploration of the SSp. Each marking can be generated with the state transition function $\vec{m}_n = \vec{m}_c + (\vec{B} - \vec{A}) \times \vec{\sigma}$. In the formula $\vec{m}_c$ is the current marking, $\vec{m}_n$ is the next marking, and $\vec{\sigma}$ is a firing count vector representing the number of times every transition has fired. For additional details about PN the reader is addressed to [12].

Due to the SSp explosion problem many times complete exploration is neither practical nor feasible. However, a raw estimation of the number $r_{m_0}$ can be calculated from the superset $\Omega$ of the SSp of the PN system as:

$$\hat{r}_{m_0} = \prod_{n=1}^{i} (q_n + 1).$$

In the formula $q_n$ is the token capacity of the $i$ place.

Also, it is not easy to calculate the maximal number of tokens $k_{m_0}$ that could exist among all the configurations of the SSp without complete exploration, but a raw estimate using the superset $\Omega$ is calculated as

$$\hat{k}_{m_0} = \sum_{n=1}^{i} (q_n).$$

## 2.2 Marked Graph Petri Net

The pre-conditions of a transition $t$ are in the set of input places $\bullet t$ and the post-conditions in $t\bullet$. The pre-events of a place $p$ are in the set $\bullet p$ and the post-events in the set $p\bullet$.

A marked graph is a PN such that $|\bullet p| = |p\bullet| = 1 \ \forall p \in P$, i.e., single arc as input and output for each place.

For the case of the SSp of an Marked Graph Petri Net (MGPN) system having places with infinite token capacity, by assigning a fixed value to $q_n$ we can estimate $r_{m_0}$ and $k_{m_0}$. We will not explain how to obtain the estimators $\hat{r}_{m_0}$ and $\hat{k}_{m_0}$; nevertheless for an understanding in these matters the reader is addressed to the theory and results from [3, 4, 9, 16–18].

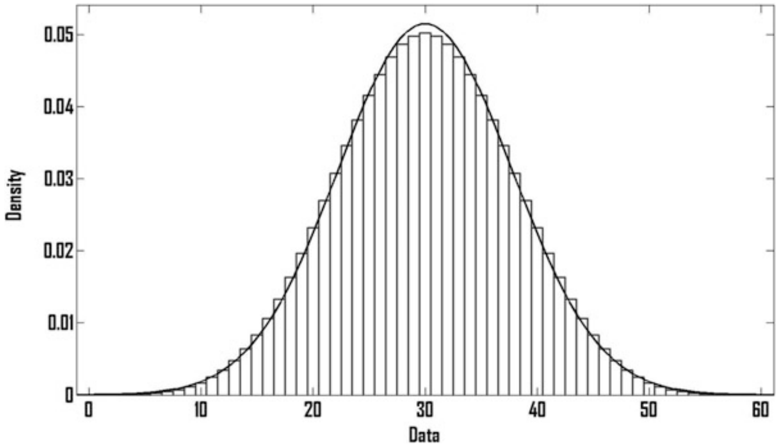


**Fig. 1.1** A histogram of an arbitrary $X$

In the rest of this section we will assume $\hat{r}_{m_0}$ and $\hat{k}_{m_0}$obtained from the superset $\Omega$ are refined estimations of the SSp of an MGPN system with initial marking $m_0$ such that the differences $\hat{r}_{m_0} - r_{m_0} \geq 0$ and $\hat{k}_{m_0} - k_{m_0} \geq 0$.

## 2.3 Probability Distribution of the Variable X of the Superset

For any marking $m \in \Omega$ let us define the variable $X$ as the number of tokens in $m$ (the cardinality of $m$). Independently of the number of places and the different but finite token capacity of the places of the PN, if we create a histogram of $X$ we get a distribution of frequencies which looks like the one in Fig. 1.1. The appearance of $X$ is of a normal probability distribution function, i.e., $X \sim N(\bar{x}, s^2)$ and its values the integers from 0 to $\hat{k}_{m_0}$.

For any PN, with any number of places and finite tokens capacities, any distribution of $X$ appears like a normal probability distribution. Formally, only a test of goodness of fit can confirm this statement, but in this paper the previous statement is assumed to be true.

The mean of $X$ can be estimated as $\hat{\bar{x}} = \hat{k}_{m_0}/2$. On the other hand, the variance represents a small challenge. Taken from the statistical "68–95–99.7" rule, stating that for a normal distribution of a large population nearly all the values lie within $3\sigma$ (three standard deviations from the mean), an estimator of the standard deviations is $\hat{s} = \hat{\bar{x}}/3 = \hat{k}_{m_0}/6$ (see Fig. 1.2).

A better estimator of the standard deviations involves having a factor of proportional error $\tau$ between the estimation and the real value with the form $\hat{k}_{m_0}/6\tau$. Figure 1.3 shows in ascending order the proportional error $\tau$ for 1, 10, 100, and 1,000 token capacity in the places, respectively.

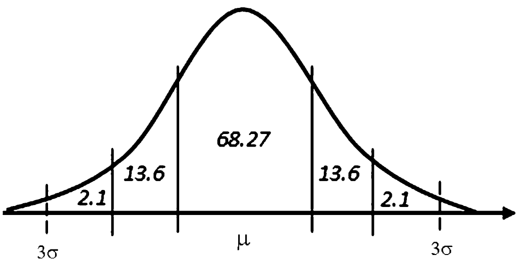


**Fig. 1.2** A segmented histogram of an arbitrary $X$

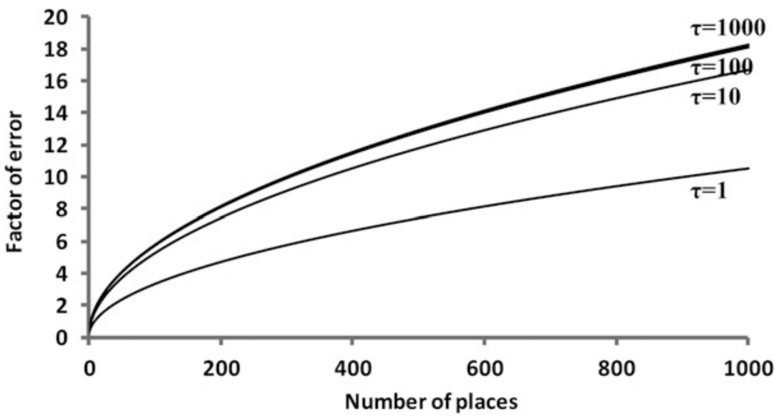


**Fig. 1.3** Proportional error between estimated and real variance

The error $\tau$ can be estimated with a function $\varphi \times i^{1/2}$, where $\varphi$ is a constant associated with the token capacity of the places and $i$ the number of places. The values of $\varphi$ for the 1, 10, 100, and 1,000 token capacity can be seen in Fig. 1.4.

Finally, in the rest of this chapter we are assuming for the case when $\hat{r}_{m_0} - r_{m_0} \cong 0$ and $\hat{k}_{m_0} - k_{m_0} \cong 0$, the probability distribution of $Y \cong X$ and the mean $\bar{x}_{m_0}$ and variance $s^2_{m_0}$ of $X$ are estimations of the mean $\mu$ and variance $\sigma^2$ of $Y$, respectively.

## 3 Partial Exploration by Quota Sampling

A probability sample is one for which every unit in a finite population has a positive probability of selection, but not necessarily equal to that of other units, like random (or uniform probability) samples [15].

Exploration methods, called sampling methods when there is no place for confusion, may be probabilistic or not. Random walk is the main algorithm in many probabilistic methods of SSp exploration, but so far there is no universal

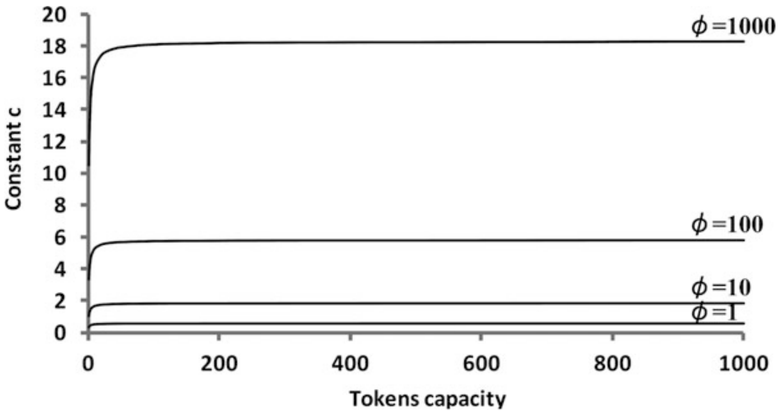


**Fig. 1.4** Values of the constant φ

solution in the framework of random walk based partial exploration methods. Moreover, the random walk cannot be considered to be random because the probability that a given state is visited is far from being uniform. Random walk as a method of SSp exploration is only useful for small models, having not practical interest in model checking, and so it is that the choice of the best exploration method is model dependent [13].

Nevertheless, non-probability samples are useful for quick and cheap studies, for case studies, for qualitative research, for pilot studies, and for developing hypotheses for future research. While random sampling allows use of statistics and tests hypotheses, non-probability (nonrandom) sampling are for exploratory research and generate hypotheses, where population parameters are not of interest (and cannot be estimated), and adequacy of the sample cannot be known due to the bias (non-probability sampling introduces unknown biases). In general, any generalization obtained from a non-probability sample must be filtered through the analyst knowledge of the topic being studied.

Non-probabilistic sampling methods appeal more to notions of representativity [14]. In this section we explain how to get a representative sample of the SSp according to the variable $Y$ which is assumed to be normally distributed. The sample is obtained with a partial exploration algorithm guided by a quota sampling [14].

## *3.1 Exploration Algorithm*

The result of our analysis is to decide whether a target marking exists or not in the SSp of a PN system. The method uses an algorithm primarily directing the exploration toward fulfilling the quotas of a table of samples while searching for the target marking $m_t$ under analysis.

First we calculate the number of states to explore (the number of samples to collect). We use the proportion $\rho$ of markings with the same cardinality as the target marking $m_t$ taken from the assumed normal probability distribution of the SSp with respect to $X$. A classical estimator to calculate the number of samples in a large population for a proportion is in the next formula, where $\upsilon$ is the confidence level (e.g., $\upsilon = 1.29$ for 99%) and $e$ is the acceptable error (e.g., $e = 0.05$ means we accept a difference up to 5% in the proportion) [2].

$$n = \frac{\upsilon^2 \rho(1-\rho)}{e^2}.$$

In our exploration, each state might be a valid sample. All samples are segmented into six mutually exclusive groups. The groups are represented in a table of quotas with six slots ($sl_g$ with $g = 1, \ldots, 6$). The table of quotas accounts only for $n$ valid samples. Each slot is used as a counter of only valid samples.

The proportion of states in a group will be applied to the quota of a slot. The proportions are taken from the assumed normal probability distribution of the SSp with respect to $Y$ with estimated mean and variance $\hat{\bar{x}}_{m_0}$ and $\hat{s}^2_{m_0}$, respectively.

The first slot $sl_1$ will account for $n \times N(\hat{\bar{x}}_{m_0}, \hat{s}^2_{m_0}; \hat{s}_{m_0})$ samples. Those are markings with cardinality less than or equal to $\hat{s}_{m_0}$.

From the second to the sixth slot ($g = 2, \ldots, 6$), they will account for $n \times [N(\hat{\bar{x}}_{m_0}, \hat{s}^2_{m_0};\ g \times \hat{s}_{m_0}) - N(\hat{\bar{x}}_{m_0}, \hat{s}^2_{m_0};\ (g-1) \times \hat{s}_{m_0})]$ samples. The markings in each slot have cardinality greater than $(g-1) \times \hat{s}_{m_0}$ and less than or equal to $g \times \hat{s}_{m_0}$.

The algorithm directs the exploration toward markings for slots with the lowest ratio of completion of their quota.

At each step of the exploration, with each sample, the algorithm takes into consideration the proportions of completeness in the previous step because it must ensure that the sample is representative of the SSp.

All unique explored markings are registered in a record of states, but only markings which are also entries in the table of quotas are valid samples. A marking with cardinality not in the range of any slot of the table is a type-1 not valid sample. A marking with cardinality of a slot with complete quota is a type-2 not valid sample. Repeated markings are discarded as samples.

The number of type-2 not valid samples is reduced by one every time a valid sample corresponding to an incomplete quota of a slot is found.

The exploration stops if the target marking is found or when all quotas are complete. In addition, the exploration stops following the same statistical "68-95-99.7" rule for detecting outliers, once the number of type-1 not valid samples is greater than or equal to 0.27% with respect to the $\hat{r}_{m_0}$.

Also, the exploration stops if the number of valid samples plus the number of type-2 not valid samples are greater than $n$. This number is artificially imposed to put a limit to the amount of collected samples (visited states) in the range of the assumed distribution of the SSp.

Finally, it should be noted that a major restriction in our analysis is the relation between $\hat{s}_{m_0}$ and the target marking. The cardinality of the target marking must be within the limits of the assumed normally distribution of $Y$.

$$\hat{\bar{x}}_{m_0} - 3\hat{s}_{m_0} \leq card(m_t) \leq \hat{\bar{x}}_{m_0} + 3\hat{s}_{m_0}$$

Although the restriction limits the analysis scope of our method, it gives robustness to the outcome given the assumed probability distribution of the variable $Y$ of the SSp.

### 3.2 Sampling Result

In theory, any random sample taken from a normally distributed population should give a normally distributed sample. In practice, we cannot take a random sample from the exploration of the SSp of a PN system. However, by using a quota sampling strategy, we can direct our exploration toward getting the result of a random sampling, a pseudo-normally distributed sample.

The sample taken with the table of quotas can be seen as a set $\Psi$ of markings. The distribution of a variable $W$, cardinality of the markings in the set $\Psi$, appears like a pseudo-normal probability distribution, i.e., $W \sim N(\bar{x}_w, s_w^2)$.

For each marking $m$ in the set $\Psi$ let us define the binomial variable $Q$ as follows:

$$Q = \begin{cases} 1 & if\ card(m) = c \\ 0 & if\ card(m) \neq c \end{cases}$$

For a target marking $m_t$ with cardinality of $c$, $q$ is the proportion of markings in the sample with the same cardinality as $m_t$.

## 4 Standard Hypothesis Test

In our reachability analysis, in searching a target marking $m_t$ with cardinality of $c$, the partial exploration algorithm fills in the quota of samples for a table of $n$ markings from the SSp.

Just for the case of unsuccessful search of the marking $m_t$, the explored states filling the quotas of the six slots belong to a set $\Psi$ of samples. Those samples can be treated with a hypothesis test.

### 4.1 State of Nature

Suppose we have a refined estimation for $r_{m_0}$ and $k_{m_0}$ taken from the superset $\Omega$ such that $\hat{r}_{m_0} - r_{m_0} \cong 0$ and $\hat{k}_{m_0} - k_{m_0} \cong 0$ and positive, where the estimators of the parameters of the mean $\mu$ and standard deviation $\sigma$ of the variable $Y$, cardinality of the markings and normal probability distribution from the set $\Psi$ of the SSp, are $\bar{x}$ and $s^2$, respectively, of the variable $X$.

The parameter $\theta$ is the proportion of markings with cardinality of $c$ in $\Psi$. An estimation of $\theta$ is calculated with the probability $N(\bar{x}_{m_0}, s^2_{m_0}; c)$.

If the estimation $\hat{\theta}$ is such that $\hat{\theta} - \theta \cong 0$ and positive, then the maximal number of markings with cardinality of $c$ in $\Psi$ is $\hat{\theta} \times n$.

### 4.2 Hypothesis Test for Proportions

We want to decide if the proportion of markings in the SSp with the same cardinality of $m_t$ is greater than the estimated proportion $\hat{\theta}$. For that we conduct the following hypothesis test for proportions:

$$H_0 : p = \hat{\theta}$$
$$H_1 : p > \hat{\theta}$$

The testatistic computed for the hypothesis test of proportions is

$$\pi = \frac{q - \hat{\theta}}{\sqrt{q(1-q)/n}}.$$

The decision obtained with this hypothesis test will be: if we reject $H_0$ it means with a $1 - \alpha$ level of significance that other markings with cardinality $c$ exist in the SSp. But if we cannot reject $H_0$ it means there might not be other markings with the same cardinality as the target marking in the SSp, therefore upon unsuccessful search the target marking might not be in the SSp of the PN system.

An additional advantage of our analysis method is that, even in the case of stopping the exploration before completing the quota sampling, sometimes is still possible to conduct a hypothesis test with the partial results upon confirmation with a test of goodness of fit that the sample represents a normal distribution.

## 5 Evaluation

We have observed correct results of the hypothesis test with the following types of PNs [10], like the MGPN in the Fig. 1.5.

Let us take a larger step toward formal verification. In what is next we will extend the results to larger networks by combining the three networks presented before. We prepared some simulations designed in order to cope with some possible scenarios for some target markings with different cardinality.

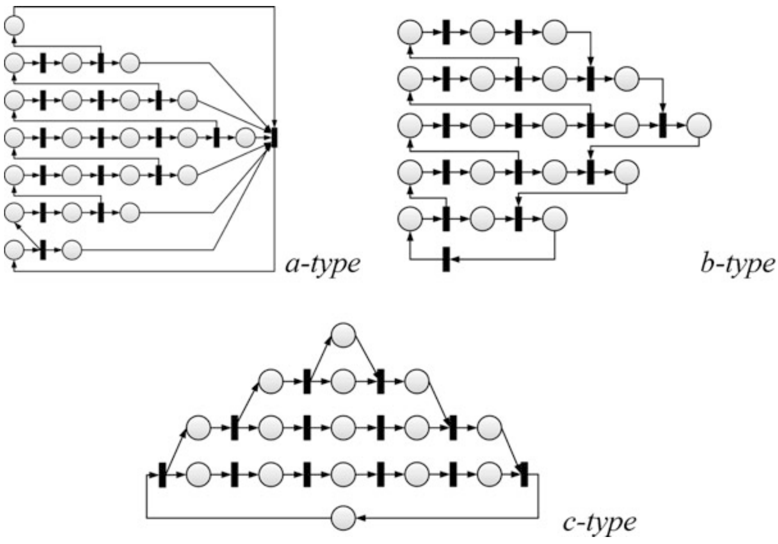


**Fig. 1.5** Marked graph Petri nets

We search for the sample requirements rejecting $H_0$. We look through the smallest acceptable error $e$ in the proportion less than or equal to 5%. Our target was to obtain a representative sample with traversal coverage, meaning in our case reaching an SSp exploration of less than or equal to 90% of the entire SSp and a sample with maximal size equal to 20% of the SSp.

We used good estimations of the mean and the standard deviation of the variable $Y$, where the dimension in the error of the estimations is smaller than 0.1 for the mean and the standard deviation.

Two samples were obtained for each reachability problem by conducting a breadth-first and depth-first search exploration. We compared the results of both algorithms to know which one conducts a better exploration toward markings with same cardinality as the target marking.

A hypothesis test rejecting $H_0$ means the proportion of markings in the SSp with same cardinality as the target marking is larger, indicating in the case of unsuccessful search that such marking might exist in the unexplored portion of the SSp. It also means that the algorithm does not visit enough markings with cardinality of $c$.

Tables 1.1 and 1.2 have the results of some explorations of the SSp for markings with certain cardinality, using the breadth-first (upper result) and depth-first (lower result) algorithms.

We use a 95% level of significance in our hypothesis test. The standard normal $z$-table gives a value of 1.645. A result from the testatistic greater than this value rejects $H_0$.

**Table 1.1** Results for card $(m_0) = 1$ with estimations of $\hat{\hat{x}}_{m_0} = 7.2$ and $\hat{s}_{m_0} = 1.6$

| Card $(m_t)$ | $e$ | Explored (%) | Sampled (%) | Testatistic |
|---|---|---|---|---|
| 5 | 0.04 | 79 | 11 | −1.35 |
| | 0.04 | 67 | 11 | 0.42 |
| 6 | 0.05 | 85 | 12 | **2.54** |
| | 0.05 | 87 | 12 | −3.31 |
| 7 | 0.05 | 85 | 14 | −3.67 |
| | 0.05 | 87 | 14 | 0.54 |
| 8 | 0.05 | 85 | 13 | **2.90** |
| | 0.05 | 87 | 13 | **2.92** |
| 9 | 0.05 | 79 | 9 | −0.02 |
| | 0.04 | 86 | 14 | −2.37 |

**Table 1.2** Results for card $(m_0) = 4$ with estimations of $\hat{\hat{x}}_{m_0} = 7.2$ and $\hat{s}_{m_0} = 1.6$

| Card $(m_t)$ | $e$ | Explored (%) | Sampled (%) | Testatistic |
|---|---|---|---|---|
| 5 | 0.04 | 71 | 11 | 0.42 |
| | 0.04 | 72 | 14 | 0.49 |
| 6 | 0.05 | 92 | 11 | **2.03** |
| | 0.05 | 72 | 12 | −2.29 |
| 7 | 0.05 | 92 | 14 | −4.25 |
| | 0.05 | 72 | 14 | −0.09 |
| 8 | 0.05 | 92 | 13 | **2.92** |
| | 0.05 | 72 | 13 | **2.92** |
| 9 | 0.05 | 70 | 8 | −0.02 |
| | 0.05 | 36 | 8 | −1.38 |

## 6 Conclusion and Future Work

A common problem for statisticians is calculating the sample size required to yield a certain power for a test given a predetermined level of significance. Compared with other sampling method, ours is somehow more intricate because in addition we must find how not to explore the entire SSp while getting the sample.

Obtaining a representative sample of markings from an MGPN system with the desired SSp coverage is possible but highly dependent on the exploration algorithm. Only simple depth and breadth search algorithms were used in our experiments guided by fulfilling the sampling quota. After the results we understood that a more sophisticated guidance in the exploration could largely reduce the portion of the exploration, especially since the cardinality of the initial markings also plays a major role in the result of any algorithm, as shown in the results of the two tables.

Despite the SSp exploration is not a process of randomly generated independent markings, the approach by quota sampling allows us to confirm the highly possible appropriateness of the hypothesis test in order to add completeness to unsuccessful searches, but just in MGPN systems with the three forms presented here. The results belong to rather small MGPN systems and the simulations do not exhaustively cover all possible scenarios, but the usability of the test in larger networks and other scenarios is straightforward.

The usage of the hypothesis test presented here is important because it statistically shows if it is significant to continue the search of the target marking. In addition, with our method, we can identify the best exploration algorithm by their effectiveness on rejecting $H_0$. From the results we can observe the breadth-first algorithm rejects $H_0$ more times than depth-first by one, meaning the second one reached more markings with the cardinality of the target marking.

Finally, since reachability has been completely characterized, the future success of our research relies in the transformation of more general PN into MGPN like the ones used here. With this, our exploration method could be used with any type of PN.

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