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Evaluation of Optimal Checkpoint Interval Maximizing Availability

Gyung-Leen Park, Bong Kyu Lee and Chul Soo Kim
Department of Computer Science and Statistics, Cheju National University, Cheju, Korea

Abstract

While various checkpointing schemes have been widely used to reduce the recovery time when a fault occurs, the problem of evaluating the optimal checkpoint interval that maximizes the availability of the system has been a critical research issue for decades. The evaluation can be done by developing analytical models with restrict assumptions. However, the analytical model has reached its limitations as the checkpointing schemes become complicated. This paper proposes to use stochastic Petri net model for the evaluation and shows the effectiveness of the approach using case studies. The paper develops stochastic Petri net models and shows how to obtain the optimal checkpoint intervals for systems employing two widely used checkpointing schemes: Checkpoint with Rollback Recovery scheme for uniprocessor systems and Primary Site Approach for multiprocessor systems.

1. Introduction

Various checkpointing schemes have been widely used to reduce the recovery time when a fault occurs [1,2]. Systems employing checkpointing approach periodically save their states to a reliable storage (checkpointing), and when a fault occurs the systems roll back to the last checkpoint and re-execute all the operations since the checkpoint. The interesting parameter here is the optimal checkpoint interval. If the checkpoint interval is too long, the availability of the system decreases due to the long recovery time when a fault occurs. If the checkpoint interval is too short, the availability of the system also decreases due to the checkpointing overhead. Evaluation of the optimal checkpoint interval for systems employing various checkpointing schemes has been a critical research issue for decades.

For uniprocessor systems, Checkpoint with Rollback Recovery (CRR) scheme has been widely used. It is assumed that the faults are all transient faults in the CRR model. The faults are also assumed to be spontaneously detected and a rollback process is initiated simultaneously [3,4].

Expansions of the CRR scheme, such as Primary Site Approach, have been proposed for multiprocessor systems. The primary site approach is a similar approach used in distributed systems [5,6]. The primary site approach assumes multiple processors and permanent faults.

Evaluations of the optimal checkpoint interval for systems employing various checkpointing schemes can be done by developing analytical models with restrict assumptions. However, the analytical model has reached its limitations, as the checkpointing schemes become more complicated. The paper proposes to use stochastic Petri net model for the evaluation and shows the effectiveness of the approach using case studies. The paper develops stochastic Petri net models for the system employing two widely used checkpointing schemes: checkpoint with rollback recovery scheme for uniprocessor systems and the primary site approach for multiprocessor systems. Then the paper shows how to obtain the availability of the systems from the stochastic Petri net model. The optimal checkpoint interval is the checkpoint interval maximizing the availability. The paper assumes that the total time of normal operations of the system between successive checkpoints is an exponentially distributed random variable. The assumption is reasonable as pointed out in [4].

The organization of this paper is as follows. A brief introduction of stochastic Petri net is presented in Section 2. The stochastic Petri net model for CRR scheme is presented in Section 3. The stochastic Petri net model for the primary site approach is presented in Section 4. Finally, Section 5 concludes this paper.

2. Stochastic Petri Net Models

Petri nets are graphical models used to present and analyze complex systems with interdependent components [7]. The formal definition of a Petri net (PN) is as follows.

A Petri net is a tuple, PN = (P,T,A,M,W) where
$P=\{p_1, p_2, \cdots, p_m\}$ is a finite set of places,
$T=\{t_1, t_2, \cdots, t_n\}$ is a finite set of transitions,
$A=\{P\times T\}\cup\{T\times P\}$ is a set of arcs,
$M=\{M_1, M_2, \cdots, M_m\}$ is a set of marking.
$W: A\rightarrow\{1,2,3,\cdots\}$ is a weight function,
$P\cap T=\emptyset$ and $P\cup T\neq\emptyset$

The marking is a distribution of tokens in each place and changed according to each transition. A reachability tree is a tree in which each node represents each distinct marking and the tree is linked by the firing of transitions. A Petri net model can be extended to a stochastic Petri net in which each transition fires according to the exponentially distributed transition rates. The formal definition of stochastic Petri net is as follows.

SPN = (P,T,A,M,W, θ)
$\theta=\theta_1, \theta_2, \cdots, \theta_n$
P,T,A,M,W are defined same as above.

The notation, θ, is the set of exponentially distributed firing rates associated with the transitions. Stochastic Petri nets are isomorphic to continuous time, homogeneous Markov chains [8]. In particular, K-bounded Petri nets are isomorphic to finite Markov chains. The marking of the stochastic Petri net correspond to the states of the Markov chain. Thus a stochastic Petri net can be analyzed based on the equivalent Markov chain. Even though the Markov chain is a very powerful tool, it is impractical to model even moderate size of a system because of the generation of too large number of states. Thus the paper proposes to use stochastic Petri net model approach to evaluate the optimal checkpoint interval for various checkpoint schemes.

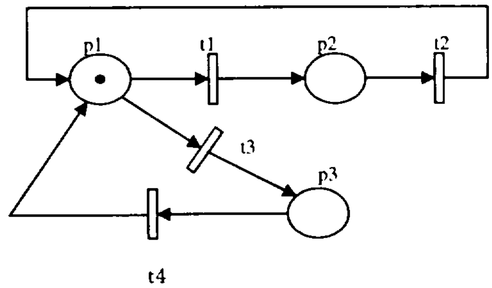
The stochastic Petri net approach consists of three steps. The first step is to develop a stochastic Petri net model that represents the behavior of the system with the target checkpointing scheme. The second step is to transform the stochastic Petri net model to its isomorphic continuous time

Markov chain. The last step is to obtain any interesting performance parameter from the Markov chain. Availability is one of the performance parameter that can be directly obtained from the Markov chain. The second and third step can be done automatically using some tools [9]. Thus, the first step is the only work needed for the evaluation. The result from the stochastic Petri net should be very close to the result of any simulation because the stochastic Petri net represents the behaviors of the target system as pointed out in [8].

3. Optimal Checkpoint Interval for Roll-back Recovery Scheme

In CRR scheme, a system can be in one of the following three states: normal state, checkpointing state, and recovery state. During the normal state, the system is doing normal operations which serves user requests. During the checkpointing state, the system is copying states of the system to a reliable storage and thus the system can not serve user requests. It is assumed that the checkpoint in reliable storage is not tempered with by any fault. During the recovery state, the system is re-executing all the operations since the last checkpoint to maintain consistency of the system and thus user requests cannot be served during this time interval. User requests which arrive to the system during this time period will be served in the next normal state. The stochastic Petri net model representing CRR scheme is in Figure 1.

The initial marking is [1 0 0] which means that the system is in the normal state. When time-out occurs by transition t_1, the system is ready for the checkpointing at state p_2. Then the system takes checkpoint by transition t_2. After the checkpointing, the system returns to the normal state, p_1. A fault may happen during the normal state by transition t_3. Then the system is ready for recovery at state p_3. After recovery occurs by transition t_4, the system returns to the normal state, p_1.



p1 : srystem is available
p2 : ready to checkpoint
p3 : ready for recovery
t1 : time out (rate = c)
t2 : checkpoint (rate = h)
t3 : failure occurs (rate = f)
t4 : recovey (rate = $2cu/\lambda$)

Figure 1. SPN model for CRR scheme.

Obtaining the reachability tree from the stochastic Petri net, the Markov chain from the reachability tree, and steady-state probabilities from the Markov chain can be done automatically using some tools [9]. The interested readers may refer to [8]. Thus, only the development of the stochastic Petri net model will be explained in the applications shown later. We will use the following example to show how to obtain the optimal checkpoint interval in actual applications.

Example: Consider a system of which mean time to failure is exponentially distributed with the expected values of 700000 seconds ($f = \frac{1}{700000}$). The expected arrival rate is 6 requests per second ($\lambda = 6$)and the expected service rate is 8($\mu = 8$). They are all Poisson processes. Since there are $\frac{\lambda}{2c\mu}$ user requests needed to be re-executed on the average, in the case of fault, the mean recovery time is $\frac{\lambda}{2c\mu}$ (the rate is $\frac{2c\mu}{\lambda}$). The cost of checkpoint is 0.5 second (h = 2). We are interested in the optimal checkpoint interval that maximizes the availability. Table 1 shows the optimal interval and the maximum availability obtained from the stochastic Petri net model in Figure 1.

Table 1. Optimal checkpoint interval and maximum availability for CRR scheme.

Optimal Interval	Max. Availability
966.3	0.998966

4. Optimal Checkpoint Interval for Primary Site Approach

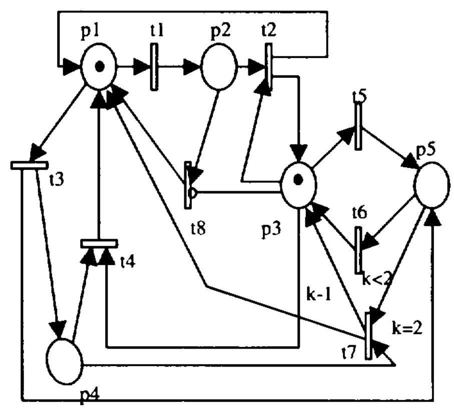
In the primary site approach, the system has three states and the definitions of them are as follow [6].

Working State: This is a state in which at least one primary site is working to provide normal services. The primary site may fail. If it happens, one of the backup processors takes over the responsibility of the primary site if there is any available backup processor. If there is no available backup processor when the primary fails, the total failure occurs and the system goes into the idle state.

Idle State: This is a state in which there is no working processor. Thus the system can not provide normal services and the user requests that arrive to the system in this state are queued outside of the system. The system needs to be repaired.

Total-Recovery State: After the system has been repaired, the system executes all the user requests that are in the queue for recovery. Thus the system can not provide normal services during this time period. The user requests that arrive to the system during this state will be served in the next working state. This paper considers the immediate repair model.

Since the primary site periodically checkpoints its state to many backups, the performance also varies according to the communication protocol used. For example, if broadcasting is used, the checkpointing cost to N back-up processors is the same as the checkpoint cost to one back-up processor, *1/h*. If point-to-point communication is used, the checkpoint cost is *N/h*. We consider both broadcasting and point-to-point communication in this paper. The stochastic Petri net in Figure 2 represents the SPN model for the system with the primary site approach.



p1 : a primary is working
p2 : ready to checkpoint
p3 : a backup processor is available
p4 : recovery request
p5 : faulty processors exist
t1 : time out (rate = c)
t2 : checkpoint (rate = h)
t3 : failure occurs (rate = f)
t4 : recovery (rate = $2c\mu/\lambda$)
t5 : failure occurs (rate = f)
t6 : repair (rate = r)
t7 : repair from total failure (rate = $t/m5$)
t8 : continue execution when no backup is available

Figure 2. SPN model for primary site approach.

In the model, the availability is the probability that place p_1 contains a token because the token in place p_1 represents a currently working primary processor. The token in place p_3 represents the back-up processor. The primary may fail and be recovered by transition t_3 and transition t_4, respectively. The backup processors also may fail and be repaired by transition t_5 and transition t_6, respectively. If there are two tokens in place p_5, the system is in the total failure state. Then all the faulty processors are repaired by transition t_7 that brings the system to the initial state. Transition t_6 is fired when the number of tokens in place p_5 is less the number of initial of markings while transition t_7 is fired when the number of tokens in place p_5 is same as the number of initial markings.

After transforming the stochastic Petri net in Figure 2 to its isomorphic Markov chain, the optimal checkpoint interval is obtained as shown in Table 2. The example was used again with a slight modification that there are N processors, and mean time to failure is same, $\frac{1}{\gamma}$, for all processors. The repair time is exponentially distributed with mean 4000 second (the rate, $\gamma = \frac{1}{4000}$).

Table 2. Optimal Checkpoint Interval in Primary Site Approach

N	optimal interval (broadcasting)	Optimal interval (p-to-p)
2	965.4	965.4
3	965.4	1360.9
4	965.4	1670.4
5	965.4	1930.3
6	965.4	2158.9

5. Conclusion

Analytical models have been used for evaluation of the optimal checkpoint interval that maximizes the availability of the system employing a checkpointing scheme. However, the analytical model has reached its limitations as the checkpointing schemes become more complicated. The system itself is also being complicated with the development of complicated technologies and distributed environments. The paper proposes to use stochastic Petri net model for the evaluation to deal with the complexities being added.

The paper has developed stochastic Petri net models for two typical checkpointing schemes, Checkpoint with Rollback Recovery scheme for uniprocessor systems and Primary Site Approach for multiprocessor systems, as case studies. Then the paper shows how to obtain the optimal checkpoint interval that maximizes the availability of the system. The result from the stochastic Petri net should be very close to the result of any simulation because the stochastic Petri net represents the behaviors of the target system. Stochastic Petri net model will be one of the most promising approaches for the optimal checkpoint interval analysis as the checkpointing schemes become more and more complicated.

References

[1] Gyung-Leen Park, Hee Yong Youn, and Behrooz Shirazi, Checkpointing with Sample Comparison for Reliable Parallel Systems, International Conference on Parallel and Distributed Computing Systems, pp. 59-64, Oct. 1997.

[2] Gyung-Leen Park, Hee Yong Youn, and B. Shirazi, Duplex with Self-Test: A Roll-Forward Checkpointing Scheme for High Performance Computing, High Performance Computing Symposium, pp. 314-319, April 1996.

[3] K. M. Chandy and C. V. Ramamoorthy, Rollback and recovery strategies for computer

programs. IEEE Transactions on Computers. vol 21. pp. 546-556. June 1972.

[4] E. Glenbe and D.Derochette. Performance of rollback recovery system under intermittent. Communications of ACM. vol. 21. pp. 493-499. June 1978.

[5] P. A. Alsberg and J.D.Day. A principle for resilient sharing of distributed resources. International Conference on Software Engineering. October 1976.

[6] Yennun Huang and Pankay Jalote. Effect of fault tolerance on response time analysis of the primary site approach. IEEE Transactions on Computers. vol. 41. no. 4. April 1992

[7] J. L. Peterson. Peri Net Theory and the Modeling of Systems. Prectice-Hall. Inc.. Englewood Cliffs. N.J.. 1981.

[8] M. k. Molly. Performance analysis using stochastic Petri nets. IEEE Transactions on Computers. vol. C-31. no. 9. pp. 913-917. Sep. 1982.

[9] A. M. Johnson and M. Malek. Survey of software tools for evaluating reliability. availability. and serviceability. ACM Computing Surveys. vol. 20. No.4. Dec. 1988. pp. 227-269.

가용성을 최대화하는 최적의 체크포인트 인터벌 분석

박 경 린 · 이 봉 규 · 김 철 수
제주대학교 자연과학대학 전산통계학과

요 약

폴트 발생시의 회복시간을 감소시키기 위하여 다양한 체크포인트 기법들이 제안되는 동안, 시스템의 가용성을 최대화 시키는 최적의 체크포인트 인터벌을 분석하는 작업은 지난 수 십년 동안 중요한 연구과제였다. 현실을 제한하는 가정 하에 분석적 모델들이 제시되었으나, 체크포인트 기법들이 점점 복잡해짐에 따라서 그 분석적 모델들은 한계를 노출하고 있다. 본 논문은 최적의 체크포인트 인터벌을 찾아내기 위하여 스토캐스틱 페트리 네트를 이용한 성능평가 방법을 제안하고, 실례를 통하여 그 효과성을 검증한다. 본 논문은 널리 쓰이고 있는 두 가지 체크포인트 기법 - 유니 프로세서 시스템을 위한 Checkpoint with Rollback Recovery 기법과 멀티 프로세서 시스템을 위한 Primary Site Approch- 에 대한 스토캐스틱 페트리 네트 모델을 제시하고 그 모델들로부터 최적의 체크포인트 인터벌을 찾아내는 방법을 보인다.