# Reliability Of Computer Systems During Physical And Informational Recovery Of Duplicated Memory

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### Abstract

The analysis of the influence of various requirements for the continuity of the computing process and the safety of information after failures on the reliability of a fault-tolerant computer system, including a computing node with two redundant storage devices connected to it, is carried out. The peculiarity of restoring storage devices is the need for both their physical and subsequent information recovery, that is, entering the information lost after a failure. Three variants of system recovery disciplines are considered, taking into account physical and informational memory recovery. For the first option, the recovered information is not unique and can always be loaded into the physically restored memory from some external source. For the second option, the information accumulated during the operation of the system can be entered into physically restored memory only based on using replicas of information stored in the system. The loss of all copies of the unique data may lead to the inability to restore the information, and as a result, to an unrecoverable failure of the computer system. The third option requires ensuring the continuity of the computing process, which is possible with the operability of the computing node and the availability for it of at least one functioning of the two storage devices containing up-to-date information. A Markov model of a computer system is proposed that reflects the stages of physical and informational recovery of duplicated memory for different criticality of the system to data loss due to memory failures.

### Keywords 1

the computer system, redundancy, recovery, continuity of the computing process, availability coefficient Introduction.

## 1. Introduction

Computer systems operating in real-time, especially as part of cyber-physical systems, have high requirements for reliability, fault tolerance, readiness [1-5], and timeliness of servicing requests [6-10]. In real-time systems, in some cases, to support functional safety and reliability, it is necessary to ensure the continuity of the computing process and the timeliness of servicing requests in case of failures and intentional impacts [11-13]. The timeliness and continuity of the computing process are ensured when reserving data storage and processing facilities and can provide for redundant query service [14,15]. It should be noted that the redundancy of the computing process, in addition to ensuring its reliability, timeliness, and continuity, allows you to implement control based on comparing the results of calculations. Computer systems of responsible use may also have increased requirements for the safety of information, in this case, redundancy (in the simplest case, duplication) of storage devices with data

replication in them is applied. The peculiarity of restoring storage devices is the need for both their physical and subsequent information recovery, that is, entering the information lost after a failure that is required to perform the functional tasks assigned to the system. Recovery of information after physical recovery of the memory of a failed device can be based on the use of replicas accumulated during the execution of application tasks in a non-failed device. The loss of all replicas of unique data can lead to the inability to restore information and, as a result, to an unrecoverable failure of the computer system. To increase the reliability of information stored in computer systems, RAID arrays are widely used, for which Markov models are known that take into account the features of information recovery [16, 17].

When designing modern complex computer systems for responsible purposes, there is a tendency to use a model-oriented approach that allows, based on modeling and optimization of the design solutions under consideration, to ensure a high level of reliability and efficiency of the systems being developed [18,19]. In the model-oriented design of real-time systems, when building reliability models, it is important to take into account various requirements for ensuring the continuity of the computing process and the safety of information after failures [14, 15, 20, 21].

The purpose of this article is to build reliability models focused on the justification of design decisions while ensuring the continuity of the computing process and the safety of information accumulated during the operation of the system with memory reservation.

## 2. Construction of Reliability Models for Physical and Informational Memory Recovery

As an object of research, a computer system is considered, including a computing node with two redundant (duplicated) storage devices (memory blocks) connected to it.

The proposed model of computer system reliability takes into account the two-stage memory recovery. At the first stage, the physical recovery of memory is carried out, and at the second, its informational recovery is carried out. The construction of storage devices based on the use of RAID array technology has not been implemented [16, 17].

Let's consider three options for organizing the recovery of information and the system as a whole, taking into account various requirements for ensuring the continuity of the computing process and the safety of information after failures.

For the first option, we will assume that the information being restored is not unique and can always be entered into the physically restored memory from some source.

For the second option, we will assume that the information being restored is unique and can be entered into physically restored memory only based on replicas stored in a non-failed storage device. If two storage devices fail, the information cannot be restored to the physically restored storage device, which may lead to the inability of the system to function, that is, to its failure (transition to a state of non-recoverable failure).

For the third option, we will assume that it is necessary to ensure the continuity of the computing process, which is possible if the computing node is operational and at least one of the two storage devices containing up-to-date information is available for it.

Markov models of reliability for the first, second, and third variants of the computer system organization are represented by diagrams of states and transitions according to Fig. 1, Fig. 2, and Fig. 3.

We encode the system states in the form $(x_1, x_2, x_3)$. At the same time, if the computing unit is healthy, then $x_1=1$, and if it failed, then $x_1=0$. Variables $x_2, x_3$-display the states of memory blocks, while the states are highlighted in which the memory block is operational -"1", failed - "0", physically restored, but the required information is not entered in it - "$F$". States are invariant to the numbering of memory blocks (for example, states «101» and «110» are considered identical). The probabilities of the system state are denoted as $P_1, P_2,.., P_8$. The presented diagrams indicate the failure rates and recoveries of the computing block $\lambda_1$ and $\mu_1$, the failure rates of memory blocks $\lambda_2$, and the intensity of their physical and information recovery $\mu_{21}$ and $\mu_{22}$.
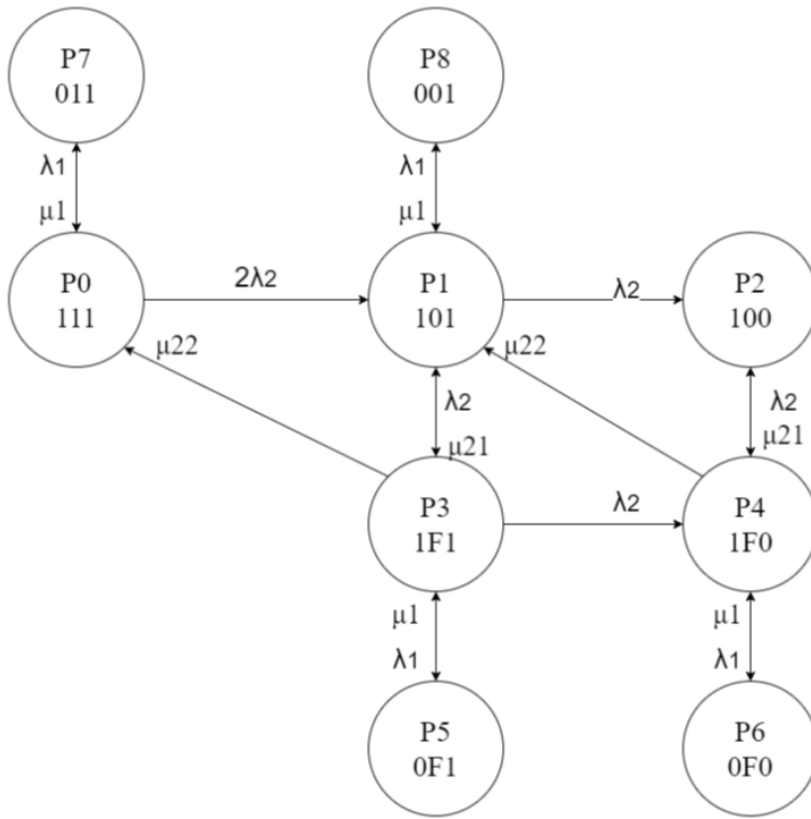
**Figure 1**: Markov model of a computer for physical and informational recovery of duplicated memory

The presented diagrams of states and transitions allow us to create a system of algebraic or differential equations, the solution of which allows us to determine the probabilities of all states of the system. As a result, it is possible to determine the dependence of the probability of system operability on the time of its operation, as well as the stationary and non-stationary availability coefficient for the restored systems.

For example, for the diagram of states and transitions in Fig. 1, the system of differential equations has the form:

$$-(2\lambda_2 + \lambda_1)P_0(t) + \mu_1 P_7(t) + \mu_{22} P_3(t) = P_0(t)',$$

$$-(\lambda_2 + \lambda_1 + \mu_{21})P_1(t) + \mu_1 P_8(t) + \mu_{22} P_4(t) + 2\lambda_{22} P_0(t) + \lambda_2 P_3(t) = P_1(t)',$$

$$-\mu_{21} P_2(t) + \lambda_2 P_1(t) + \lambda_2 P_4(t) = P_2(t)',$$

$$-(\mu_{22} + 2\lambda_2 + \lambda_1)P_3(t) + \mu_{21} P_1(t) + \mu_1 P_5(t) = P_3(t)',$$

$$-(\mu_{22} + \lambda_2 + \lambda_1)P_4(t) + \lambda_2 P_3(t) + \mu_{21} P_2(t) + \mu_1 P_6(t) = P_4(t)',$$

$$-\mu_1 P_5(t) + \lambda_1 P_3(t) = P_5(t)',$$

$$-\mu_1 P_6(t) + \lambda_1 P_4(t) = P_6(t)',$$

$$-\mu_1 P_7(t) + \lambda_1 P_0(t) = P_7(t)',$$

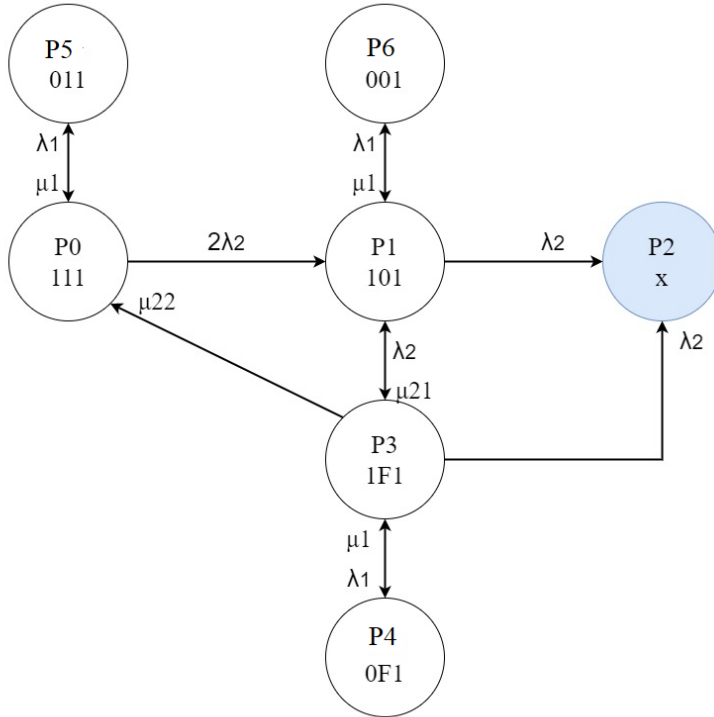$$-\mu_1 P_8(t) + \lambda_1 P_1(t) = P_8(t)'.$$

**Figure 2**: Markov model of a computer for physical and informational recovery of duplicated memory
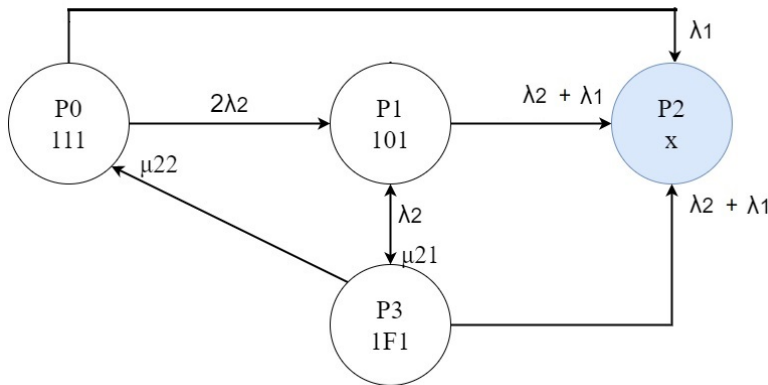


**Figure 3**: Markov model of a computer with the criticality of the continuity of the computational process

For the diagram of states and transitions according to Fig. 3, the system of differential equations has the form:

$$-(2\lambda_2 + \lambda_1)P_0(t) + \mu_{22}P_3(t) = P_0(t)',$$
$$-(\lambda_2 + \mu_{21})P_1(t) + 2\lambda_2 P_0(t) + \lambda_2 P_3(t) = P_1(t)',$$
$$\lambda_1 P_0(t) + (\lambda_1 + \lambda_2)P_1(t) + (\lambda_1 + \lambda_2)P_3(t) = P_2(t)',$$
$$-(\mu_{22} + 2\lambda_2 + \lambda_1)P_3(t) + \mu_{21}P_1(t) = P_3(t)',$$

The non-stationary readiness coefficient (the probability of the system's readiness to function without interrupting the computing process due to failures or loss of information) is defined as

$$k(t) = P_0(t) + P_1(t) + P_3(t),$$

Note that the stationary readiness coefficient for the variants corresponding to Fig.3 and Fig.2 is zero, and for the variant, according to Fig.1 it is not zero.

## 3. Example of Calculating the Reliability of a Computer System

An example of calculating the non-stationary availability coefficient of computer systems with duplicated storage devices is shown in Figure 4, where Curve 1 corresponds to the non-stationary availability coefficient $k$ of a system that is not critical to data loss, and curve 2 corresponds to the non-stationary availability coefficient of a system that is critical to the loss of unique data. Curve 3 corresponds to the difference in the probability of operability $d$ between the options critical to the loss of information and the preservation of the continuity of the computational process. The calculation was performed at $\lambda_1 = 10^{-4}$ 1/h, $\lambda 2 = 2 \cdot 10^{-4}$ 1/h, $\mu_1 = 1$ 1/h, $\mu_{21} = 1$ 1/h, $\mu_{22} = 11$ 1/h.

The presented dependencies confirm the significance of the influence of the factors under consideration on the reliability of the computer systems under study.
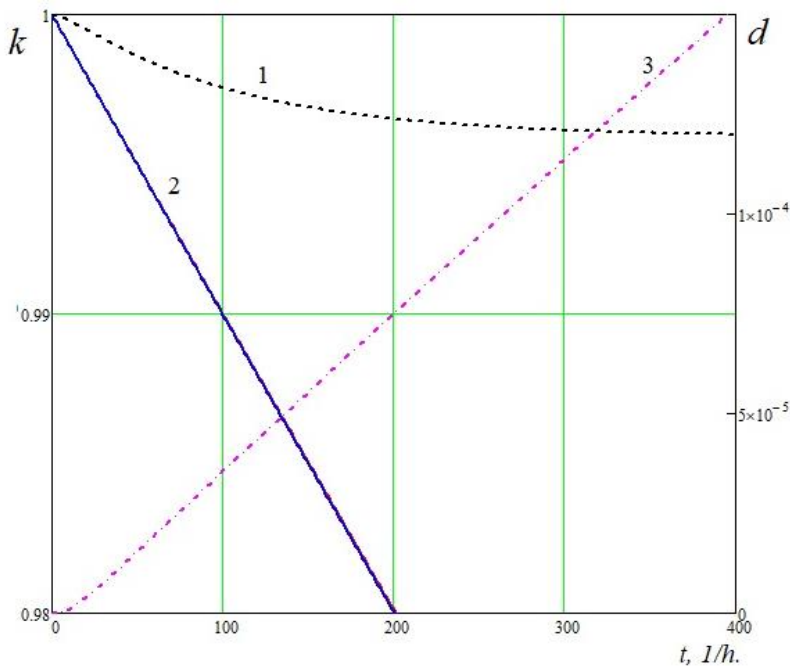


**Figure 4**: Calculation of the non-stationary availability coefficient of computer systems with duplicated storage devices

## 4. Conclusions

For computer systems of cluster architecture operating in real-time, efficiency criteria are proposed and the possibilities of increasing the overall efficiency of servicing requests of heterogeneous traffic are shown based on the replication of waiting-critical requests and the allocation of a group of nodes for their servicing of certain types of requests for acceptable waiting delays.

An analytical model is proposed and the efficiency of redundant service options is determined with the possible allocation of cluster nodes to solve the most critical waiting requests in queues.

It is shown that there is a region of efficiency of reserved servicing of latency-critical requests when dividing cluster nodes into groups designed to service requests of different latency criticality.

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