TECHNISCHE UNIVERSITEIT EINDHOVEN
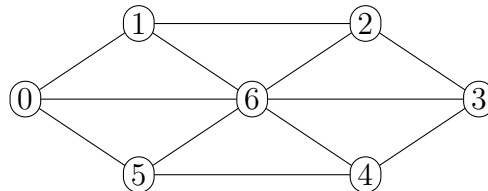**Faculteit Wiskunde en Informatica**

Examination Architecture of Distributed Systems (2IMN10),
on Thursday, November 9, 2017, from 13.30 to 16.30 hours.

Before you start, read the entire exam carefully. Answers to all questions must be motivated and stated clearly. For each question the maximum obtainable score is indicated between parentheses. The total score sums up to 20 points. This is a closed book exam, i.e., you are not allowed to use books or other lecture material when answering the questions.

1. (2 points) Describe the peer-to-peer (P2P) architectural style using the appropriate vocabulary. Name the concepts and rules involved, give a motivation for its usage, and mention typical behavior and its weak points.

   Answer. See slide 13 of the slide set on architectural styles. A weak point would be security, e.g. access control, which is easier to realize in a centralized architecture.

2. A protocol for accessing a given replicated distributed data store with at least one correct node is *t-read-resilient* (*t-write-resilient*), when, in the presence of at most t faulty nodes, all clients that contact a correct node can perform a read (write) operation. Consider a replicated distributed data store with 7 nodes connected in the following way:

   (a) (0.5 point) Determine respectively the maximum *read-resilience* and the maximum *write-resilience* (maximum values of t), in case this data store uses a quorum-based protocol with $R = 1$ and $W = 7$. Assume that in every operation a client communicates with only a single node of the data store, which is therefore responsible for assembling the quorum. Also beware that a faulty node is *incapable* of performing routing actions necessary to assist a correct node in assembling a quorum.

   (b) (0.5 point) The same question for $R = 2$ and $W = 6$.

   (c) (0.5 point) The same question for $R = 3$ and $W = 5$.

   (d) (0.5 point) The same question for $R = 4$ and $W = 4$.

Answer. Due to its topology the data store has the following properties:

- In case there are at most two faulty nodes, the data store remains connected. If the central node remains correct, all other correct nodes are connected via a path through it. In case the central node is faulty, there is at most one faulty node on the outer ring, hence the remaining correct nodes form a line or ring. So, in this case, each correct node can obtain a quorum with size equal to the number of correct nodes.

- In case there are at least three faulty nodes, these can occur such that the data store becomes partitioned. In particular a remaining correct node on the outer ring becomes isolated when all three of its neighbors are faulty. Such a node can only obtain a quorum of size 1, namely itself.

From these observations it follows that

(a) In case $R = 1$ and $W = 7$, the protocol is 6-*read-resilient* and 0-*write-resilient*.

(b) In case $R = 2$ and $W = 6$, the protocol is 2-*read-resilient* and 1-*write-resilient*.

(c) In case $R = 3$ and $W = 5$, the protocol is 2-*read-resilient* and 2-*write-resilient*.

(d) In case $R = 4$ and $W = 4$, the protocol is 2-*read-resilient* and 2-*write-resilient*.

3. Tactics are architectural solutions to ascertain desired qualities of a system. Following an approach introduced by Bass, Kazman and Clements, quality concerns are expressed by means of so-called quality scenarios. Consequently, the architectural description then contains one or more tactics for each of these quality scenarios.

   (a) (1 point) What are the generic ingredients that describe a tactic given the approach sketched above?

   Answer. First, there are the inputs to the tactic that originate from the quality scenario. They fall in two categories: inputs associated with the stimulus, which are the nature of the stimulus and the source of the stimulus, and inputs that originate from the system, which are the state of the system when the stimulus occurs and the artifacts, i.e. parts of the system affected by the stimulus. Second, there are the guaranteed outputs of the tactic as specified by the scenario, i.e., the response itself and a measure of that response indicating a quality level. Finally, the tactic itself, which provides the mechanism to realize the quality concern, consists of a set of architectural elements and their interaction pattern.

   (b) (1 point) Give, in global terms, a tactic description that deals with a security scenario that stipulates prevention of eavesdropping.

   Answer. The system artifacts are the message source, the message sink and the communication channel between them. The considered state is an ongoing communication session between the source and the sink. The stimulus is a

tap on the communication channel imposed by an intruder, the eavesdropper (source of the stimulus) The tactic consists of encryption of the message. So the architectural elements are an encoder at the source, a decoder at the sink, and possibly some infra-structure to obtain encryption keys. The guaranteed output is that the eavesdropper cannot decypher the message (response), unless he spends a certain minimal amount of computational effort (measure).

4. (2 points) Describe in detail how the URL

   http://www.win.tue.nl/home/wsinmak/Education/2IMN10/ADS.html

   is resolved. In particular, indicate the closure mechanisms, and resolution procedure for the various parts of the URL.

   Answer. This URL consists of three components: a scheme **http** that names a protocol, a hostname **www.win.tue.nl** that identifies the host holding the resource, and a pathname **home/wsinmak/Education/2IMN10/ADS.html** that identifies a file (the resource) on that host. It is resolved as follows. The browser extracts the scheme and based on the value found invokes its Http_client, which is a plugin in the form of a library. This Http_client resolves the hostname by contacting its local DNS-server to obtain an IP-address. The local DNS-server may invoke other DNS-servers to assists in resolving the hostname (see TvS for a description of how this works), but in case the local DNS-server happens to be the TU/e DNS-server it will know the IP-address. Next, the Http_client will set up a connection with the host machine, construct an appropriate http-request (GET) containing the pathname and invoke the operating system to send the request to the web server at the host machine. Finally, this web server resolves the pathname to obtain the resource and returns a representation of it to the browser.

5. Consider the Chord scheme for DHTs. Assume a 6-bit identifier space, and assume that the node set N is given by $id(N) = \{2, 13, 28, 35, 54, 60\}$.

   (a) (0.5 point) Give the finger table of node 28.

   Answer. For a 6-bit identifier space all finger tables have 6 entries. Table FT_{28} is given by:

   $FT_{28}[1] = FT_{28}[2] = FT_{28}[3] = 35$, $FT_{28}[4] = FT_{28}[5] = 54$, and $FT_{28}[6] = 60$.

   (b) (1.0 point) Assume that node 2 is removed. This requires modification of the finger tables of the remaining nodes. Indicate for each of these nodes which entries of its finger table need to be modified and what their new values should be.

   Answer. Since the next node on the ring after node 2 is node 13, all finger table entries whose value is 2 have to be changed to 13. No other entries need to be modified. For node p and index i with $1 \leq i \leq 6$, entry $FT_p[i] = 2$ if and only if $60 < (p + 2^{i-1}) \mod 64 \leq 2$, or equivalently $60 - p < 2^{i-1} \leq 66 - p$. For

nodes $13, 28, 35$, there is no index i that satisfies this criterion. For node 54 the criterion becomes $6 < 2^{i-1} \leq 12$ which has the single solution $i = 4$ and finally for node 60, the criterion becomes $0 < 2^{i-1} \leq 6$ which has solutions $1 \leq i \leq 3$.

(c) (0.5 point) Indicate a key k for which resolution starting at node 28 requires a different number of steps before and after removal of node 2. Also give the resolution sequence before and after removal. You may assume that every node is aware of the identity of its predecessor.

Answer. Assuming that node 28 is aware that node 13 is its predecessor, it "knows" that it is responsible for keys k with $13 < k \leq 28$ itself, and resolves those keys in zero steps. This does not change when node 2 is removed. For keys k with $28 < k \leq 60$, the resolution process will only consult finger table entries on nodes $28, 35$ or 54 that are unmodified. Hence, for these keys, the resolution stays the same. So, the only keys for which the number of resolution steps changes are the ones for which resolution changes from $28 \rightarrow 60 \rightarrow 2 \rightarrow 13$ before removal of node 2 to $28 \rightarrow 60 \rightarrow 13$ after removal. It follows that the key should be larger than 2 but smaller than 13. For any key in this range, the number of resolution steps decreases by one. Note that for $60 < k \leq 2$ the number of resolution steps stays the same, although resolution changes from $28 \rightarrow 60 \rightarrow 2$ to $28 \rightarrow 60 \rightarrow 13$.

6. Component-based software engineering uses predefined components to realize distributed systems.

   (a) (0.5 point) Give the definition of a software component.

   Answer. See slide 10 of the slide set on CBSE.

   (b) (1.5 point) Motivate the usage of components for system design, i.e., name at least three properties that facilitate or otherwise make it attractive to build complex systems from predefined components.

   Answer. See slides 5 and 6 of the slide set on CBSE.

7. Bondi distinguishes 4 types of scalability.

   (a) (1 point) One of these types is space-scalability. Give its definition.

   Answer. According to Bondi a system exhibits space scalability, if its memory requirements do not grow to intolerable levels as the number of items supported increases (memory increases sublinearly!).

   (b) (1 point) Explain why a columnar representation of a database may contribute to space-scalablity.

   Answer. Each column of a database table holds the values of a specific attribute. If such an attribute can assume only a small number, say n of distinct values, but there are many more, say $N \gg n$, rows in the table, then, in general, each of these values occurs multiple times in a column. Sorting and

run-length encoding will then results in a significant reduction (from $\mathcal{O}(N)$) to $\mathcal{O}(n)$ of storage space for a column. Note that it is not uncommon for a single attribute to assume only a limited number of values, e.g., day-of-the-month, forename, etc. On the other hand, opportunities for row compression are scarce.

8. Indicate for the following statements whether they are true or false. Motivate your answer with a short argument.

   (a) (0.75 point) Absence of client-oriented consistency breaks replication transparency.
   Answer. True.
   Replication transparency means that users of a resource or service cannot detect that it is replicated. In the absence of client-oriented consistency users (clients) of a replicated data store may observe an unexpected state. Assuming that the data store operates correctly and other clients do not intentionally provide misinformation, such as for instance replying to non-existing messages, the most plausible explanation then is that they currently interact with a replica different from the one with which they interacted in the past.

   (b) (0.75 point) For Web server clusters, TCP handoff and content-aware request distribution are incompatible.
   Answer. False.
   The handoff can be done in two stages. First, any server of the cluster is contacted by the "TCP-switch" according to its scheduling policy, which is not content-aware. Instead of dealing with the client's request, however this server invokes a dispatcher that determines, based on the message content, the most suitable server in the cluster to handle the request. The TCP-connection is then handed-over to that server and the switch is informed of this fact. (see Note 3.8, vST 3rd ed. or Page 559, TvS 2nd ed. for details).

   (c) (0.75 point) Architectural frameworks are only meant for architectural styles, not for interaction styles.
   Answer. False.
   Although frameworks usually address architectural styles, they can be more restricted and be dedicated to only an interaction style. The DCE RPC framework is an example of the latter.

   (d) (0.75 point) A closure mechanism describes how to finalize the resolution process.
   Answer. False.
   A closure mechanism defines where and how to start the resolution process.

   (e) (0.75 point) For software aboard of a spacecraft availability is a more important quality attribute than reliability.
   Answer. False.
   Availability addresses readiness for correct service, whereas reliability addresses

continuity of correct service. In circumstances where system repair is impossible or extremely difficult, as in spacecrafts, failure usually amounts to loss of the system. Reliability, which postpones failure, is therefore the more important quality attribute.

(f) (0.75 point) Software maintainability issues are best addressed in the deployment view

Answer. False.

Software maintenance is made more easy by software modules with clear and limited responsibilities and few dependencies on other modules. This are typically issues that are addressed in the development view.

(g) (0.75 point) Remote method invocations in CORBA use mediated discovery for locating the remote object.

Answer. True.

The client-side stub holds a reference to the object that needs to be resolved. For this it uses a broker, the ORB.

(h) (0.75 point) The quality of a system architecture is decided by the system's stakeholders.

Answer. True.

Although the architect develops the architecture, the stakeholders need to be convinced that their concerns regarding the system are met. So, in the end, they decide how good an architecture is.