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ADVANCED APPROACH TO PRODUCTION WORKFLOW COMPOSITION ON ENGINEERING KNOWLEDGE PORTALS

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The paper presents an approach to production workflow composition on engineering knowledge portals. The conceptual model of engineering knowledge portal is proposed, allowing to systematize and structure the information and computing resources of the portal; as well as a formal algebraic system for production workflow composition is proposed, allowing to set the context-independent formal structures for production workflow elements description. The approach to production workflow composition is developed as ordered tree forming method that allows to integrate partial calculation tasks into general calculation of engineering portal, performed on user request demand. The real world scenario «Calculation of the strength for the power components of magnetic systems» is represented, approving the applicability and efficiency of proposed approach.

Introduction

Research results of independent agencies Gartner Group and Real Story Group [1] for 2011-2012 show that one of the major trends in the development of content management is moving from simple structure sites to large integrated sites of corporate knowledge.

These sites contain a description of the different scientific, engineering or industrial tasks, information about methods of solving or providing services to implement them. They also provide users with navigation search and extension of the displayed content with user required detailing.

Integration of data and computing resources by using portal solutions that contain links to geographically distributed resources, allow not only access the information resources, stored in their databases, but also, using data, knowledge and services to implement certain computational tasks. When the number of links to different information and computing resources becomes large enough, the efficient management of information and computing processes becomes almost impossible.

Besides, a number of information and computing resources can dynamically change their location and it is not always possible to manage this process centrally. Thereby the problem of efficient management of information and computing processes on the portal appears. Solving this problem would provide solution for the high-technology and intellectual tasks in various areas, but for the engineering field such solution is extremely relevant.

Knowledge portal introduction

Knowledge portal is an integrated portal designed to provide meaningful access to structured data and portal knowledge. Information, concentrated in knowledge portals environment makes their usage very common. Thus, technically, knowledge portal should provide integration and collaboration of services, databases and knowledge bases, information storages and computing resources, as well as provide the integration of:

- production processes,
- workflows,
- computing tasks.

In order to provide the correct and holistic interaction of all elements in a single production workflow the mechanism of their integration is required.

Systematization and structuring of information and computing resources on the knowledge portals for their effective interaction are studied by Straccia, Guarino, Cohen, Sowa, Zagorul'ko Yu. and others [2-8]. For instance, ontological model [9, 10] is used as knowledge representation model for knowledge portals in the field of archeology and computer linguistics. Ontology allows to describe portal information objects and their information environment, but still some tasks remain unsolved, which are:

- formal description of the portal model as an integrated mathematical system;
- integrating information resources and services to compose a workflow, representing a separate calculation task of the portal [11].

Usually, ontologies are meta-descriptions of the computing and information resources elements. However, the portal workflow design requires selecting from the portal elements set the ones, required for the specific workflow execution. Such task is not trivial and is realized via portal production workflows composition (WFC).

Some considerable number of researches have been recently done on the WFC topic [12]. As well as more specific field has been previously analyzed, which is QoS-aware WFC [13]. Several state-of-the-art studies have shown that most of existing WFC approaches do not cover a sufficient number of QoS subjective parameters. Another important issue is lack of the monitoring phase, meaning that resulting service will fail and won't satisfy the user in case of failure of WF any component.

Thus, the production workflows composition is limited with the following problems:

- impossible to describe metadata of engineering knowledge portal elements clearly structured because these knowledge are created by different groups of scientists, they are unrelated by general formalized rules of knowledge representation, various technologies and tools of knowledge representation are used;
- no unified mechanism for information and computing resources integration;
- inability to describe the characteristics of computing and information resources depending on the particular subject area because of their interdisciplinary nature;
- inability to describe the workflows because some separate works are used to form various engineering calculation tasks.

Solution of the specified problems requires the development of:

- the conceptual model of the engineering knowledge portal;
- a formal apparatus allowing efficient production workflow design;
- the approach to production workflow composition.

Conceptual model of the engineering knowledge portal will allow systematizing and structuring both portal information and computing resources. The formal apparatus, being formal algebraic model of the production workflow, will allow to develop a formal

context-independent framework for production workflow elements description.

The approach to production workflow composition will allow, using formal algebraic model of the production workflow, to implement a workflow composition into production workflow, providing formal representation and execution of the calculations to solve complex engineering tasks on the portal.

The conceptual model of the engineering knowledge portal

Engineering knowledge portals are sets of the specific elements, forming users workflow, which are:

- informational resources;
- workflows, which can be production workflows, which are a complete complex engineering task.

The complex structure of the portal is composed by nested and hierarchical calculation tasks. Portals include great amount of production workflows that themselves consists from separate workflows.

Thus, the following conceptual model of the engineering knowledge portal is proposed (1):

$$CM(P) = \{PWF, IR, WF\} \quad (1)$$

Where CM – conceptual model, P – portal, PWF – production workflow, IR – information resources, WF – workflow.

To provide knowledge portal functioning, production workflows should be designed and implemented as they are realizing complete complex engineering tasks. Formally, production workflow can be represented as:

$$PWF = \{CWF, IR, WF, MD\} \quad (2)$$

Where CWF – complex workflow, IR – information resources, WF – workflow.

MD – meta-description.

Each of WF and PWF has a specific set of attributes, describing its features and characteristics. Such set forms the set of meta-descriptions. Meta-descriptions allow to automate the process of production workflow composition based on the parameters and characteristics of a particular engineering problem domain [14]. Meta-descriptions and their attributes allows to identify each WF in unique way. Meanings of meta-descriptions attributes are stored in database that is filled during preliminary description of WF. Specification of WF meta-descriptions is based on Dublin Core standard and defines meta-description as $M = \langle A, D \rangle$, where A is meta-description attribute (represent important characteristic or parameter of WF) and D is data (represent the name of this parameter or characteristic for appropriate WF). For example, if we describe the

set of meta-descriptions of WFs that represent specific engineering portal calculation tasks, they could have such meta-description attributes as title, element material, element_on_calculation, etc. For each calculation task meanings of attributes (that represent data - D) would be different. Thus, if we consider attribute “element_on_calculation” for WF “Strength calculation” the data for this attribute will be - “structure carcass”, but for WF “Stability calculation” the data for the same attribute will “support structure”.

The following meta descriptions, representing the various characteristics of calculation tasks are specified below (table 1).

Table 1. Workflow meta-description

Standard meta-descriptions	
Attribute name	Attribute description
Title	Resource name. This element is usually a formal name, representing specific resource.
Identifier	A unique identifier. The number of WF
Subject	Narrow subject domain of the specific WF application
Description	Textual description of the WF
Data	Data type, which WF contains
Domain-specific meta-descriptions	
Parameter	The parameters, used for calculations
Loading	The loads, used in calculations
Methods	Calculation methods
Element	Calculation element
Measurement area	Constructs squares, for which formula calculations are relevant or which are calculated in formula or which appear in the calculation
Connecting meta-descriptions	
Regulatory	Title of the normative document (GOST, ISO, calculation standards), which is associated with a WF
Calculation	Calculation (functional element), associated with specific calculation
Address	Address, specifying calculation service allocation
Material	Materials, required for calculation

WF set is stored in an independent repository that has no semantic and logical connections with the PWF repository. Partial WF structure is similar to the PWF

structure and includes WF name and parameters. Fig. 1 represents the repository of WF and one PWF, each of them has its own structure and set of parameters.

Search of the WF, to be included into the PWF may be based on comparing WF parameters, as PWF includes only the WF, which have common parameters or parameter ranges of values are overlapped.

Let the set of PWF to be:

$$R^t \ni r_k^t, r_k^t = \langle T_k^t, p_k^t \rangle \quad (3)$$

where

R^t – PWF set

r_k^t – k-th PWF from PWF set

T_k^t – title of k-th PWF from PWF set

p_k^t – set of parameters of k-th PWF from PWF set

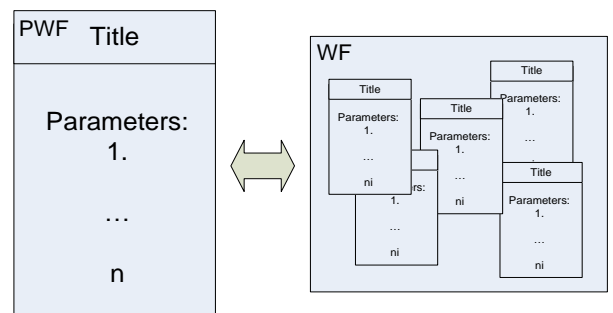


Fig. 1 PWF and WF set

WF set is:

$$R^{wf} \ni r_1^{wf}, r_1^{wf} = \langle T_1^{wf}, p_1^{wf} \rangle \quad (4)$$

where

R^{wf} – WF set

r_1^{wf} – 1-th WF from WF set

T_1^{wf} – title of 1-th WF from WF set

p_1^{wf} – set of parameter of 1-th WF from WF set

As discussed approach deals with WFs that describe calculation tasks of engineering knowledge portal, assume that each WF is uniquely identified by set of its parameters. It means that two workflows with the same parameters could not have a different semantic in what they do and meanings of WF and PWF parameters could be used for WF integration into the PWF.

Using such formal description, specific methods can be used to automate production workflow composition.

The algebraic model of production workflow

PWF formal algebraic system allows to use formal algebraic structures for PWF elements description as well as describe operations with PWF elements when engineering knowledge portal functioning. Formation of PWF and WF involves the description of all their

element, so, on the one hand such description must be oriented on the portal subject field, but, on the other hand it should be context-independent. To develop such kind of description it is suggested to use algebraic structures – objects, data sets and operations of algebra, that allows to form context-independent description of WF and PWF. Thus the use of algebraic system provides increasing of PWF formation efficiency. Such formal description will allow PWF correct and fast composition.

The algebraic model of PWF is represented by a set of certain type operations on a stored set of information and computing resources [15, 16].

The elements of the proposed PWF formal algebraic model are represented below.

Objects. Objects are the basic elements of the algebra on which all operations of algebra are conducted. In PWF algebraic model as the variety of objects set of WF are mentioned.

Data. Elements that are given to the input and output of the system, represent the data of algebra. In PWF algebraic model, such objects can be used as data: different constants, variables, results of operations, etc. On the physical level, the data are represented by:

- the values of various parameters and characteristics of the subject domain,
- formulas,
- values boundaries,
- partial services,
- computational procedures that represent calculation tasks [17].

Operations. Set of operations in the PWF algebraic model is divided into two subsets: subset of simple operations and subset of complex operations [18].

Simple operations include:

- elementary algebra operations according to the definition,
- operations on set (given in the set theory),
- logical operations defined by algebra of relations.

Complex operations are:

- the operation of parallel connection O^{pc} that describes the process of WF connection with disjunction logical operation;
- the operation of serial connection O^{sc} that describes the process of WF connection with disjunction logical operation;

- operation of logical composition O^c that allows to connect WF by means of known relationship between them and interim WF;

- operation of inversion O^i that provides a replacement of the WF order to the opposite during the connection of WF in PWF;

- matching operation O^m that allows to connect WF that are not connected explicitly using some parameters

More detailed description of proposed algebraic system is given in [19].

The approach to the production workflow composition

Proposed in section 2 and 3 models allow to develop the approach to PWF composition, allowing correctly and dynamically generate a sequence of PWF when portal functioning.

The proposed approach to PWF composition is presented as ordered tree forming method. Whereas the ordered tree is a tree with a root, which defines the order of child nodes, the use of ordered trees to represent PWF will specify the sequence of WF execution.

The suggested approach to PWF tree forming is represented on Fig. 2.

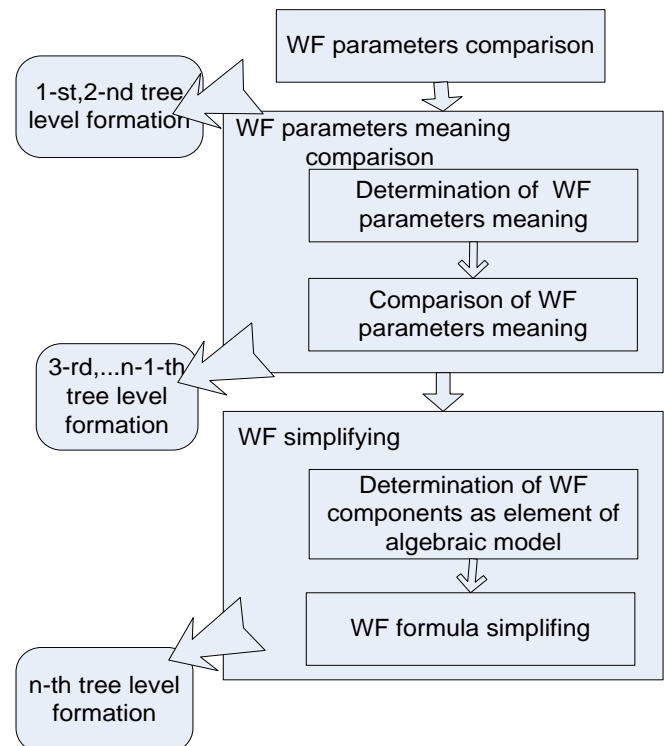


Fig. 2 Tree forming method

The stages of PWF tree forming method are represented below.

Stage 1. At the first stage it is in need to discard from the set R^{wf} those WF, for which p_{lq}^{wf} is not equal to p_{kj}^t

Stage 2. At this stage it is necessary to compare meanings of p_{lq}^{wf} to cut the subset of WF, that has common parameters but their meanings are not equal.

Stage 3. Stage 3 proposes to simplify the WF formula.

Fig. 3 shows tree, that is formed using proposed approach. The root node shows PWF, tree leaves are WF.

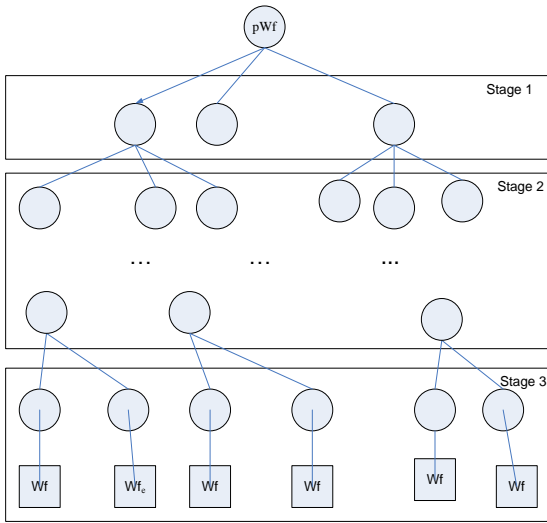


Fig. 3 PWF tree

More detailed description of the suggested approach stages is represented below.

Stage 1. Comparing WF parameters

At the first stage it is necessary to include WF into the PWF comparing and selecting the WF, which parameters match the PWF parameters. It is necessary to analyze the WF set and choose from it those WF, which parameters match the PWF parameters according to the rule:

$$P_d^t = \bigcup_i^m P_i^{wf} \quad (5)$$

whereby possible the fulfilment:

$$P_i^{wf} \cap P_j^{wf} \quad (6)$$

where $i, j = \overline{1, m}$

The result is a subset of WF set satisfying the rule (5) and PWF tree with second level tops, which are elements of this subset.

Stage 2. Checking WF parameters values

Partial WF are selected to concatenate into PWF based on comparing subsets of parameters sets corresponding to these WF. The comparisons is done based on the occurrences or equality of these parameters meaning range of values.

Thus, on the stage of WF parameter values verification WF parameters values from WF set, formed on the first stage, are compared to PWF corresponding parameters:

$$M(p_{ik}^t) <> M(p_{jt}^{wf}) \quad (7)$$

under the condition that $p_{ik}^t = p_{jt}^{wf}$

The result can be one of the following options:

1. Domains match

$$M(p_{ik}^t) = M(p_{jt}^{wf}) \quad (8)$$

in this case domain of the k-th parameter of i-th PWF matches domain of t-th parameter of j-th WF, ie specified WF is included as a node into PWF tree.

2. One domain includes another one:

2.1.

$$M(p_{jt}^{wf}) \subset M(p_{ik}^t) \quad (9)$$

in this case domain of the t-th parameter of j-th WF includes domain of k-th parameter of i-th PWF, ie specified WF is included as a node into PWF tree,

2.2.

$$M(p_{ik}^t) \subset M(p_{jt}^{wf}) \quad (10)$$

in this case domain of the k-th parameter of i-th PWF includes t-th parameter of j-th WF, ie specified WF is included as a node into PWF tree. But analysis of the parameter values for other WF continues in order to find WF, which parameter values domain in combination with this WF parameter values domain will form PWF parameter values domain.

3. Domains overlap

$$M(p_{ik}^t) \cap M(p_{jt}^{wf}) \quad (11)$$

in this case domain of the k-th parameter of i-th PWF overlap domain of t-th parameter of j-th WF, ie specified WF is included as a node into PWF tree. But analysis of the parameter values for other WF continues in order to find WF, which parameter values domain in combination with this WF parameter values domain will form PWF parameter values domain:

$$M(p_{jt}^{wf}) \cup M(p_{hd}^{wf}) = M(p_{ik}^t) \quad (12)$$

4. Domains don't overlap

$$M(p_{ik}^t) \neq M(p_{jt}^{wf}) \quad (13)$$

in this case domain of the k-th parameter of i-th PWF don't overlap domain of t-th parameter of j-th WF, ie specified WF is not included into PWF tree.

Stage 3. Simplifying WF formula

The third stage operates with specific rules and operations to represent the formula of WF (described using proposed algebraic model) in minimized form. Such simplifications rules are based on properties of operations [20]. Operations properties form the basis for the main identities of algebraic model underlying the formulas transformation for the purpose of simplification or reduction to a certain form.

The resulting PWF tree can be saved in the knowledge base as a pattern for further use with the possibility of its modification. It can be modified using standard operations on trees.

Presenting the engineering tasks in the form of PWF with tree structure allows to process each node of the tree, which represents a different WF, simultaneously, avoiding tree branches, which are independent of each other, which will minimize time for PWF composition.

Example of the production workflow composition

The example of proposed approach to PWF composition is considered below. PWF represents real complex engineering calculation task that consists of WFs that represents more simple engineering calculation tasks. Assume that there is PWF that represent engineering calculation task «Calculation of the strength for the power components of magnetic systems» with description structure:

$$r_1^t = \langle T_1^t, p_{1j}^t \rangle, j = 1, n \quad (14)$$

where

T_1^t – «Calculation of the strength for the power components of magnetic systems»

$p_{11}^t - a_1 = 10$ – allowable pressure

$p_{12}^t - E_2 = 52$ – average loading

$p_{13}^t - E_1 = 48$ – basic loading

$p_{14}^t - R = 5$ – winding radius

$p_{15}^t - c = 10$ – the length of connection between construction body and winding

$p_{16}^t - l = 15$ – critical length

$p_{17}^t - D_m = \langle 10 \dots 12 \rangle$ = maximal diameter

$p_{18}^t - P_i = 18$ – dimension of construction body

$p_{19}^t - \eta = 20$ – critical pressure

$p_{110}^t - \phi = 5$ – allowable tension pressure

$p_{111}^t - v = 28$ – winding length

$p_{112}^t - d = 44$ – winding strength

$p_{113}^t - e = 6$ – constant of static level

$p_{114}^t - M = 12$ – general membrane strength

At the 1-st stage the analysis of WF set is done. It is in need to chose from this set only those WF that satisfies condition (5). Such WF are:

1. Calculation of basic parameters: $r_1^{wf} = \langle T_1^{wf}, p_{1j}^{wf} \rangle, j = 1, n$, where: T_1^{wf} is «Calculation of basic parameters», $p_{11}^{wf} - d = 44, p_{12}^{wf} - e = 6, p_{13}^{wf} - M = 12$

2. Verifying calculation: $r_2^{wf} = \langle T_2^{wf}, p_{2j}^{wf} \rangle, j = 1, n$, where: T_2^{wf} is «Verifying calculation», $p_{21}^{wf} - a_1 = 10, p_{22}^{wf} - E_2 = 52, p_{23}^{wf} - E_1 = 48, p_{24}^{wf} - R = 5, p_{25}^{wf} - c = 10, p_{26}^{wf} - l = 15, p_{27}^{wf} - D_m = \langle 10, \dots, 12 \rangle, p_{28}^{wf} - P_i = 18, p_{29}^{wf} - \eta = 20, p_{210}^{wf} - \phi = 5, p_{211}^{wf} - v = 28$.

Some more WF are characterized by parameters similar to parameters of r_1^{wf} . They are: static strength calculation, critical constant calculation, resistance calculation:

1. Static strength calculation: $r_3^{wf} = \langle T_3^{wf}, p_{3j}^{wf} \rangle$, where T_3^{wf} – «Static strength calculation», $p_{31}^{wf} - a_1 = 10, p_{32}^{wf} - E_2 = 52, p_{33}^{wf} - E_1 = 48, p_{34}^{wf} - R = 5, p_{35}^{wf} - c = 10, p_{36}^{wf} - l = 15, p_{37}^{wf} - D_m = \langle 10 \dots 12 \rangle$.

2. Critical constant calculation: $r_4^{wf} = \langle T_4^{wf}, p_{4j}^{wf} \rangle$, where: T_4^{wf} – «Critical constant calculation», $p_{41}^{wf} - a_1 = 10, p_{42}^{wf} - E_2 = 52, p_{43}^{wf} - E_1 = 48, p_{44}^{wf} - R = 5, p_{45}^{wf} - c = 10, p_{46}^{wf} - l = 15, p_{47}^{wf} - D_m = \langle 15 \dots 52 \rangle$

3. Resistance calculation: $r_5^{wf} = \langle T_5^{wf}, p_{5j}^{wf} \rangle$, where: T_5^{wf} – «Resistance calculation», $p_{51}^{wf} - P_i = 18, p_{52}^{wf} - \eta = 20, p_{53}^{wf} - \phi = 5, p_{54}^{wf} - v = 28$

As the result, we receive the subset of WF that satisfies condition (5). Formed PWF tree is shown on Fig. 4. The root node show PWF: r_1^t – «Calculation of the strength for the power components of magnetic systems», intermediate nodes are WF: r_1^{wf} – «Calculation of basic parameters» and r_2^{wf} – «Verifying calculation», leaves are WF: r_3^{wf} – «Static strength calculation», r_4^{wf} – «Critical constant calculation», r_5^{wf} – «Resistance calculation».

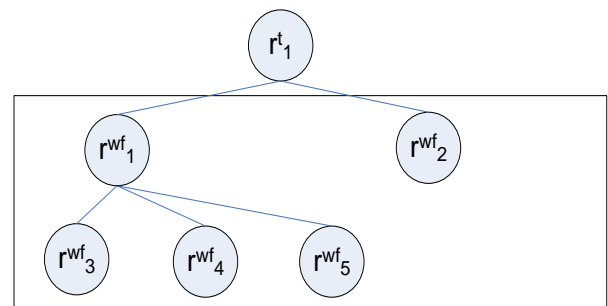


Fig. 4 PWF tree on the stage 1

At 2-nd stage, the comparison of WF parameters is held according to the rule (7):

Let us consider parameter D_m of described calculations:

– for calculation of the strength for the power components of magnetic systems:

$$D_m = \langle 10, \dots, 12 \rangle,$$

– for Verifying calculation:

$$D_m = \langle 10, \dots, 12 \rangle,$$

– for Static strength calculation:

$$D_m = \langle 0, \dots, 12 \rangle,$$

– for Critical constant calculation:

$$D_m = \langle 15, \dots, 52 \rangle.$$

Let us compare the meanings of these parameters:

$$M(p_{17}^t) \langle \rangle M(p_{27}^{wf}) \langle \rangle M(p_{37}^{wf}) \langle \rangle M(p_{47}^{wf}) \quad (15)$$

The range of value for p_{17}^t of “Calculation of the strength for the power components of magnetic systems” is equal to the range of value for p_{27}^{wf} of “Verifying calculation”. The range of value for p_{27}^{wf} of “Verifying calculation” is equal to p_{37}^{wf} of “Static strength calculation” and is not equal to p_{47}^{wf} of “Critical constant calculation”:

$$M(p_{17}^t) = M(p_{27}^{wf}), M(p_{27}^{wf}) = M(p_{37}^{wf}) \neq M(p_{47}^{wf})$$

It means that we can reduce the set of WF, excluding critical constant calculation from this set. PWF tree after 2-nd stage is shown on Fig. 5. Tree includes the same nodes and leaves as tree represented on Fig. 4, but r_4^{wf} - “Critical constant calculation” – is to be removed from the tree as the result of the 2-nd stage.

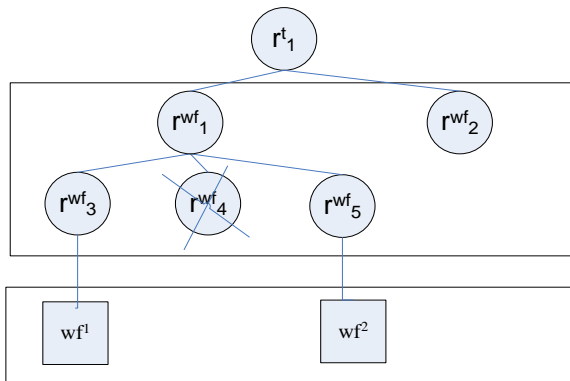


Fig. 5 PWF tree

Such example of proposed approach implementation to PWF, representing real engineering calculation task, provides the proof of correct representation and execution of complex engineering calculation tasks on the knowledge portal.

Conclusions

The paper presents an approach to PWF composition on engineering knowledge portals. A conceptual model of a knowledge portal is proposed, allowing to systematize and structure the information and computing resources of the portal; as well as a formal algebraic system for PWF composition, allowing to set the context-independent formal structures for PWF elements description.

The proposed approach to PWF composition is presented as ordered tree forming method. It allows structuring the WF and improves the efficiency of their performance through parallel processing of independent tree branches of PWF. It also allows integrating partial calculation tasks into general calculation of engineering portal, performed on user request demand.

Future work is aimed on implementation of suggested approach to different types of complex engineering calculation tasks. This will allow to approve its applicability and efficiency on real world scenarios.

Future work supposes the development of software tool for production workflow composition, their future monitoring and reconfiguration. As a basis already developed workflow design and analysis tool can be used [21] with further extension of its functionality. Developed software tool will be tested and verified on real world scenarios when developing engineering knowledge portals.

Quantitative evaluation of the proposed approach and tool efficiency will be obtained: the average time of PWF composition, PWF correctness and quality will be validated.

References

- [1] Tony Byrne, Real Story Group Blog – Digital workplace and enterprise architecture: two sides to same coin, (2012) - <http://www.realstorygroup.com/Blog/2311-Digital-workplace-and-enterprise-architecture-two-sides-to-same-coin>
- [2] John F. Sowa The role of logic and ontology in language and reasoning, Chapter 11 of Theory and Applications of Ontology: Philosophical Perspectives, edited by R. Poli & J. Seibt, Berlin: Springer, 2010, pp. 231-263.
- [3] F. Bobillo, U. Straccia. Aggregation Operators for Fuzzy Ontologies. Applied Soft Computing 13(9):3816-3830, 2013
- [4] Guarino N., Guizzardi G. In Defense of Ontological Foundations for Conceptual Modeling. In: Scandinavian Journal of Information Systems, vol. 18(1) pp. 115 - 126. 2006.

- [5] D. Movshovitz-Attias and W.W. Cohen. 2012. Boot-strapping biomedical ontologies for scientific text using nell. Technical report, Carnegie Mellon University, CMU-ML-12-101.
- [6] Zagorulko U.A. and others. An approach to portals of scientific knowledge development // *Avtometriya*. 2008. V. 44. № 1. P. 100—110.
- [7] Gavrilova T.A. Horoshevskiy V.F. Knowledge bases of intellectual systems. — S-P.: Piter, 2000
- [8] Kolb D.G. Web-oriented realization of semantic models for intellectual systems // *Proceedings of scientific conference “«Open Semantic Technologies for Intelligent Systems (OSTIS-2012)”*, - Minsk, 2012. – P. 111–122.
- [9] Globa L. Method of heterogeneous information resources structuring and systematizing for Internet portals development / Globa L., Novogrudskaya R., Oriekhov O. // In: *IEEE EUROCON*, pp. 319–326 (2013).
- [10] Zagorulko U.A. and others. The technology of scientific portals development: experience of application, problems and prospects. *Proceedings of international scientific conference «SWC-technique and telecommunication technologies» (Crymico' 2011)*. - Sevastopol: Veber, 2011. – P. 51-54.
- [11] Globa L.S., Novogrudskaya R.L., Models and methods of information and computation resources integration *Proceedings of scientific conference “«Open Semantic Technologies for Intelligent Systems (OSTIS-2012)”*, - Minsk, 2012. – P. 142-148
- [12] Pukhkaiev, D., Kot, T., Globa, L., Schill, A.: A novel SLA-aware approach for web service composition. In: *IEEE EUROCON*, pp. 327--334 (2013)
- [13] Pukhkaiev, D., Kot, T., Globa, L., Schill, A.: Yet another SLA-aware WSC System. *Lecture Notes in Business Information Processing*, Volume 176, 2014, pp 197-205
- [14] Globa L.S., Novogrudskaya R.L., The development of engineering calculations for knowledge portals // *Proceedings of scientific conference «Open Semantic Technologies for Intelligent Systems (OSTIS - 2014)»*. - Minsk, 2012. – P. 137-143
- [15] Telenyk S.F. Logic of computational processes representation in intellectual system SmartBase // *System technologies. System modeling of technological processes – 1999*. – Series. 6. – C.131 -139.
- [16] Pavlov A.A., Telenyk S.F. *Informational technologies and algorithmization in management*. – K.:Tehnika, 2002. – 344 p.
- [17] Shahovska N.B. Data space in sphere of scientific research // *Modeling and information technologies*. – 2008. – № 45. – P. 132–140
- [18] John Dwyer. *An Introduction to Discrete Mathematics for Business & Computing*. ISBN 978-1-907934-00-1. (2010)
- [19] Globa L.S., Novogrudskaya R.L., An approach to formal system for knowledge portals development, *Ontology of designing*. - 2014. - №2(11). – ISSN 2223-9537- P.40-59
- [20] Kenneth H. Rosen. *Discrete Mathematics: And Its Applications*. McGraw-Hill College. ISBN 978-0-07-288008-3. (2007)
- [21] Kot T., Reverchuk A., Globa L., Schill A. A novel approach to increase efficiency of OSS/BSS workflow planning and design. – Springer: *Lecture Notes in Business Information Processing*. – 2012. – Vol. 117. – P. 142-152.