Analysis building blocks: a rich information model context for knowledge-based finite element analysis

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Abstract

In a product design and analysis process, engineers have different usage views towards product information models. The heterogeneous transformation problem has been presented to characterize the resulting gap between design models and analysis models. The multi-representation architecture (MRA) has been developed to realize this transformation through four stepping-stone information representations, including analyzable product models, context-based analysis models, analysis building blocks (ABBs), and solution method models (SMMs).

In this paper, our primary focus is on ABBs for solid mechanics and thermal systems that generate FEA SMMs to obtain their results. ABBs, which represent the analytical usage view for analysis engineers, are constructed using an object-oriented knowledge representation known as constrained objects (COBs). ABBs represent product-independent analysis concepts such as continuum mechanics bodies and idealized interconnections as semantically rich, reusable, modular, and tool-independent objects. To demonstrate the efficacy of the ABB model, an electronic chip package thermomechanical analysis test case is overviewed. This extended ABB approach provides an effective way to capture engineering knowledge and decrease FEA modeling time.

Keywords: Heterogeneous transformation; Multi-representation architecture (MRA); Analysis building block (ABB); Solution method model (SMM); Constrained object (COB); Finite element analysis (FEA)

1. Introduction

Targeting the needs of design and analysis integration, Peak and colleagues [1–3] have proposed a general methodology for automating ubiquitous analysis to support product design. In this methodology, the multi-representation architecture (MRA) is presented to facilitate heterogeneous transformations by explicitly representing design-analysis associativity and supporting numerous diverse analysis models for each product type. The MRA consists of four stepping-stone information representations, i.e. analyzable product models, context-based analysis models, analysis building blocks (ABBs), and solution method models (SMMs). ABBs and SMMs are product-independent models that facilitate generalized mappings between a single product model and diverse analysis models. ABBs describe the theoretic physical systems, such as continuum mechanics systems, while SMMs represent ABBs in relatively low-level solution technique form, such as finite element analysis models.

In this paper, we primarily focus on ABB models for solid mechanics and thermal systems that utilize FEA-based SMMs. In the next section, we briefly introduce the MRA as the context for ABB models. In Section 3, the concept and architecture of the ABB representation is overviewed. In the context of solid mechanics and thermal system, we discuss the information needed to develop an ABB model and transform it into a corresponding SMM that uses FEA as the solution technique. Then, we show how to implement ABBs using an object-oriented knowledge representation known as constrained objects (COBs). A COB diagram is presented in Section 4 to illustrate the key attributes of ABB objects and their relationships. Finally, Section 5 presents an electronic chip package thermomechanical analysis scenario to show the efficacy of the ABB model.

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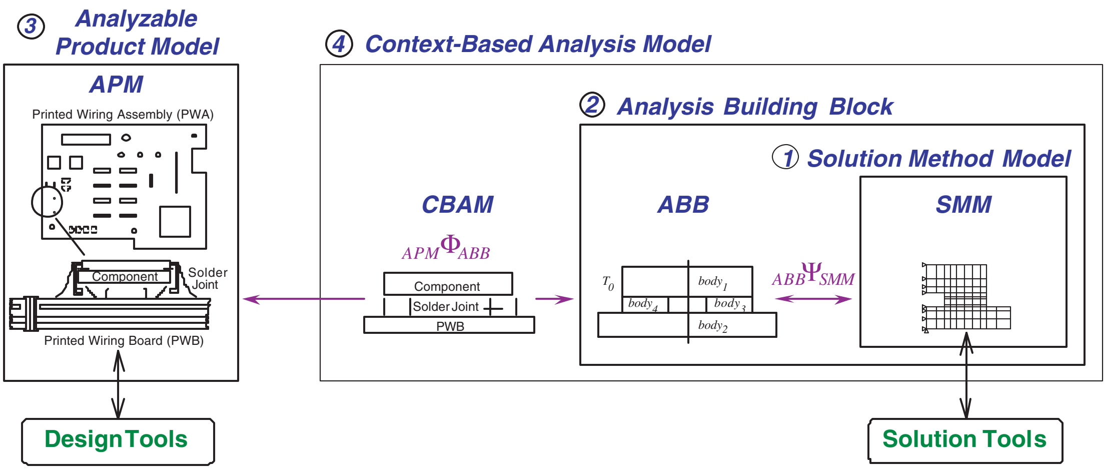

Fig. 1. Multi-representation architecture (MRA) [1–3].

2. Multi-representation architecture (MRA) context

The MRA is illustrated using a solder joint thermomechanical analysis example in Fig. 1. On the right side is a solution method module (SMM), which represents an analysis model in relatively low level and solution method specific form. An SMM combines solution tool inputs, outputs, and control into a single information entity to facilitate automated solution tool access and results retrieval. Analysis building blocks (ABBs) represent analytical engineering concepts in a manner that is largely independent of product application and solution method. ABBs obtain results by generating SMMs through transformations, ${}_{\mathrm{ABB}}\Psi_{\mathrm{SMM}}$, that are based on solution method considerations. Analyzable Product Models (APMs) represent detailed design-oriented product information. An APM is considered the master description of a product which supplies information to other product life cycle tasks, including engineering analysis and manufacturing. To enable its usage by potentially many analysis applications, an APM in the MRA goes beyond its traditional design role by supporting idealizations that relate detailed design-oriented attributes with simplified analysis-oriented attributes. Finally, a context-based analysis model (CBAM) contains linkages that represent design-analysis associativity between an APM and an ABB model, ${}_{\mathrm{APM}}\Phi_{\mathrm{ABB}}$. These associativity linkages indicate the usage of idealizations for a particular analysis application (e.g. solder joint deformation). Thus, CBAMs show how product independent ABBs are supplied with design-related information to help solve product-specific analysis problems.

From the MRA viewpoint, providing solutions to the design-analysis integration problem involves defining these four representations (SMMs, ABBs, APMs, and CBAMs) and two inter-representation mappings (${}_{\mathrm{ABB}}\Psi_{\mathrm{SMM}}$ and ${}_{\mathrm{APM}}\Phi_{\mathrm{ABB}}$.

Building within the above MRA context, this paper further develops the concepts of ABBs for solid mechanics and thermal systems, hereafter collectively referred to as “continuum systems”.

3. ABB models for solid mechanics and thermal systems

An ABB model represents engineering analysis concepts as a set of computable information entities, which are independent from specific solution techniques [1]. In the context of solid mechanics and thermal systems, ABB concepts are presented in Fig. 2. To facilitate representing a variety of continuum systems, ABB information content is categorized by composition in Fig. 2a. A continuum system consists of two key components: idealized structure and idealized loads. Structure represents any assembly of objects that supports or transmits loads, e.g. idealized building structure, aircraft, vehicles, etc. Loads represent active forces that are applied onto the structure because of external causes, e.g. pressure, vibration, temperature, etc. [4]. Both these aspects in the composition hierarchy are necessary to completely represent a continuum system.

At the next level, structure is composed of individual continua, and the interrelations between those continua are described using connectivity concepts (idealized interconnections). For instance, slip bonding between two continuum entities indicates the condition that the two continuum entities are in contact, while only relative displacement along the contact interface is allowed. Relative displacement interrelations between a structures and its environment are identified as support constraints such as rigid support, pin support, etc. ABBs are categorized by types into several levels, including analysis primitives that are used in building intermediate ABBs and analysis sys-

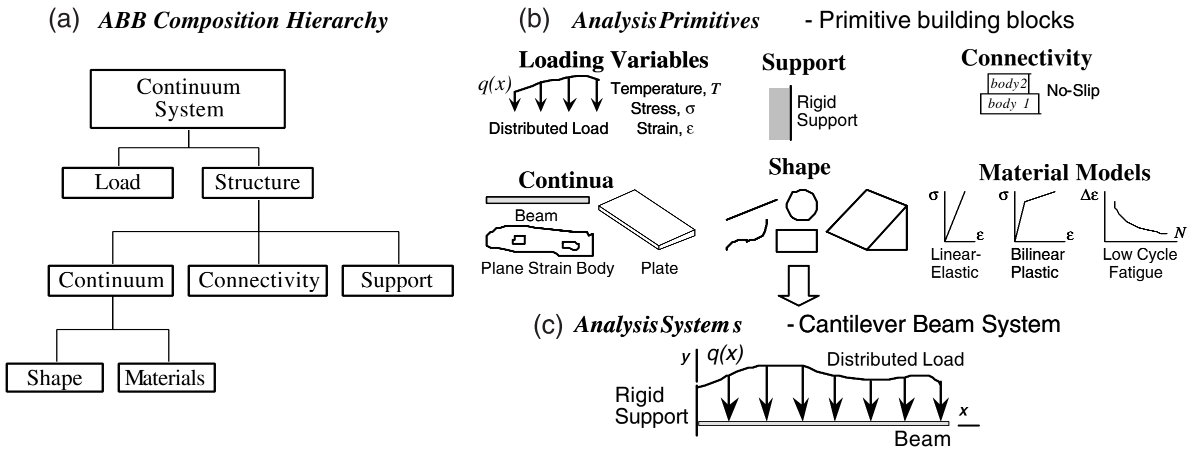

Fig. 2. Information content for example ABB concepts.

tems (Fig. 2b). For instance, shape and material models are primitive ABBs; they are combined together with other ABB concepts to represent a continuum ABB — an intermediate type of ABB primitive. An ABB system as shown in Fig. 2c for a cantilever beam analysis system is formed by assembling ABB primitives such as a loading force, a continuum beam, and a rigid support.

In the composition hierarchy given in Fig. 2a, the leaf nodes denote analysis primitive categories at the levels where they can be easily changed or reused in a plug-and-play manner, and the root node represents an ABB analysis system. Hence, an ABB model is composed of fundamental building blocks to represent all the necessary information in an analytical sense.

4. COB representation

The ABB model of a continuum system can be represented using constraint objects (COBs) [5,6]. The COB representation is a knowledge representation that employs object technology and constraint graph concepts. This modeling language provides modularity, reusability and multi-directionality and is closely matched with the way engineers interpret their interaction with an idealized environment. One of the COB representation components is the graphical Object Relationship diagram presented using Express-G notation from the ISO 10303-11 information modeling standard [7]. Fig. 3 uses this diagram to illustrate various types of ABBs, their attributes, and their object hierarchy at the template level, i.e., not at the instance level.

The partial ABB information model shown in Fig. 3 is influenced by the work of STEP Part 42 and AP210 [7]. In the ABB composition hierarchy of Fig. 2a, the root node, continuum system, is mapped to the object type *ABB Assembly* in Fig. 3. The main attributes of this object are *Connectivity*, *Loads* and *Supports*. Continua can also be defined, and they are joined in an ABB system by *Connectivity* objects. By mapping each item in the ABB concept hierarchy of Fig. 2a into a corresponding object type in Fig. 3, the information content for a class of continuum systems is fully described. This Express-G model can be formulated as a lexical Express model, which can then be turned into computable data structures [1].

The *Assembly Feature* object type represents the region on/in the specified continuum where an interconnect, load, or support is applied. Its attribute *Definition* indicates the shape of the applied region, which can be a solid, face, edge, or vertex. This attribute is an object of type *Geometric Representation Item* (from STEP Part 42) that helps to identify the location of an interconnect between two continua, or the location where a load or support is applied. Attribute *Associated_continuum* indicates the specified continuum on/in which the interconnect, load, or support is applied. Besides knowing the location of interconnects, loads, and supports and their associated continua, other properties of these instances need to be specified. For example, is an interconnect of type glue bond (i.e. no slip) or slip bond? Which degrees of freedom does the support constrain? For an analysis system, what are the idealized environment effects, such as force, temperature, and pressure? These conditions are specified as objects of type *STRING, Support Feature*, and *Loading Feature* respectively.

With the major object relationships and attributes of the ABB information model having been described above, the implementation of this model is overviewed in the next section.

[1] See, for example, ISO 10303 STEP toolkits by vendors like www.lksoft.com.

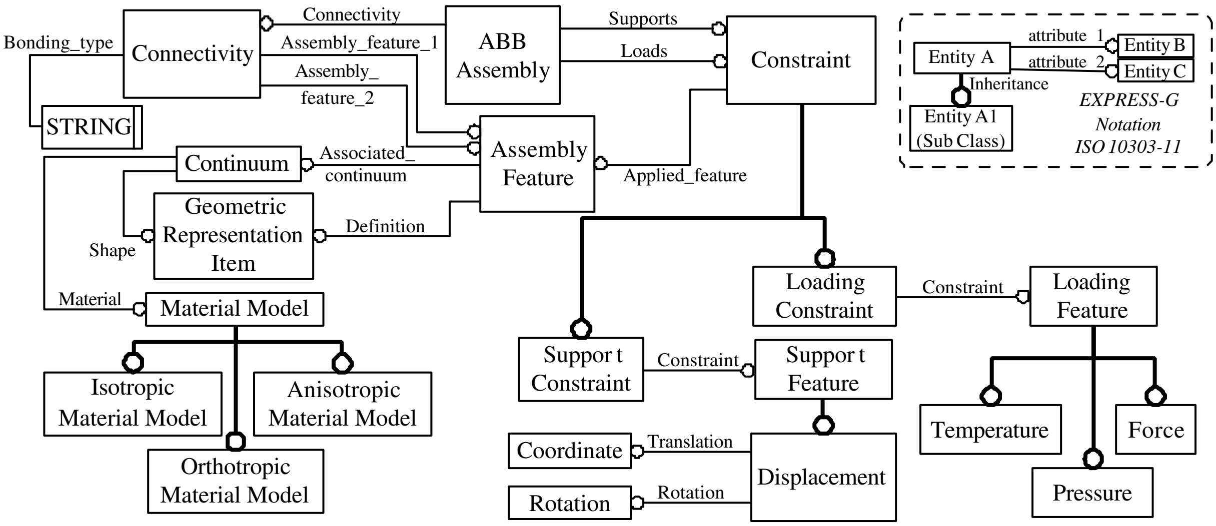

Fig. 3. Partial ABB information model

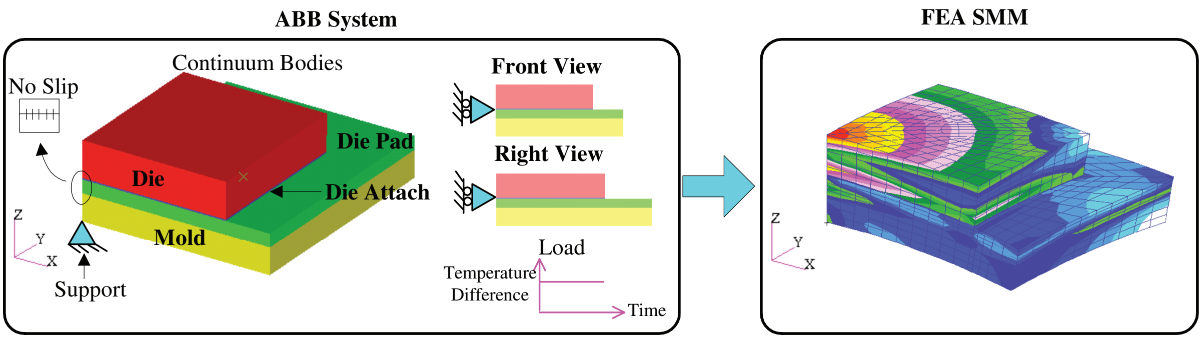

Fig. 4. A thermomechanical ABB system with FEA model for an electronic chip package.

5. Case study [2]

A simple chip package thermomechanical analysis test case is presented to illustrate the ABB modeling approach. Thermomechanical failures are caused by stresses and strain within a chip package due to thermal loading from the environment or internal heating [8]. It is one of the most important failure mechanisms that needs to be considered in package design. Given an idealized chip package, a thermomechanical ABB analysis system is shown in Fig. 4. The structure is composed of four linear elastic thermomechanical continua (i.e., die, die attach, die pad and mold), which are glue bonded in the idealized sense (i.e. no slip) to form a stackup. The supports of this structure are a rigid pin support at the corner point of the mold, and rollable pin supports on all the surfaces that are located in the XZ (front view) and the YZ (right view) planes of the coordinate system. The load applied on the structure is a uniform temperature difference, which generally causes thermal stresses as CTE (coefficient of thermal expansion) mismatches typically exist among the material models in such ABB systems.

Some ABB instances in this system are shown in Table 1 using a pseudo COB instance (COI) language. Here we do not list all the detailed information in the instances. Instead, the syntax in the table is simplified to convey only the substantial information. The table is organized in a bottom-up fashion (the reverse of Fig. 2a). First material and shape instances are defined for the idealized die. Then the die continuum body is defined, which uses these instances (e.g. the line "Material: #*si_materials_01*;" in row 3 specifies that the continuum body shall use the material instance defined in row 1 of Table 1. The other three continuum bodies are similarly defined (not shown in this table). Then example instances of a connectivity, a support, and a load

[2] See http://eislab.gatech.edu/projects/shinko/ for further information about applications to chip packages.

Table 1
Major ABBs instances for the chip package example

Row #	ABB primitive description	Attributes and values
1	Die material	Object type: isotropic material model SUBTYPE_OF material model Instance id: #*si_material_01* Name: “silicon”; Youngs_modulus: 2.001e5; Poissons_ratio: 0.33; Thermal_expansion_coefficient: 3.4e-6;
2	Die shape	Object type: Block SUBTYPE_OF geometric representation item Instance id: #*die_shape_01* X: 0.25; Y: 0.25; Z: 0.05;
3	Die continuum	Object type: continuum Instance id: #*die_continuum_01* Material: #*si_material_01*; Shape: #*die_shape_01*;
4	Die and die attach interconnect	Object type: connectivity Instance id: #*die-die_attach_interconnect_01* Assembly_feature_1.Associated_continuum: #*die_continuum_01*; Assembly_feature_2.Associated_continuum: #*die_attach_continuum_01*; Bonding_type: "glue bonding";
5	Rigid pin support at mold corner	Object type: support constraint SUBTYPE_OF constraint Instance id: #*rigid_pin_support_01* Constraint.Translation.X: 0.0; Constraint.Translation.Y: 0.0; Constraint.Translation.Z: 0.0; Applied_feature.Definition.(Cartesian Point).X: 0.0; Applied_feature.Definition.(Cartesian Point).Y: 0.0; Applied_feature.Definition.(Cartesian Point).Z: 0.0; Applied_feature.Associated_continuum: #*mold_continuum_01*;
6	Temperature load on the entire model	Object type: loading constraint SUBTYPE_OF constraint Instance id: #*temperature_difference_01* Constraint.(Uniform Temperature).Magnitude: −215; Constraint.Applied_feature.Associated_continuum: #*all_continua*;
7	The ABB system	Object type: ABB assembly Instance id: #*chip_package_assembly_01* Part_number: "600010"; Part_name: "EBGA600 thermo-mechanical model"; Physical_behavior: "structural"; Connectivity[0]: #*die-die_attach_interconnect_01*; ... Supports[0]: #*rigid_pin_support_01*; ... Loads[0]: #*temperature_difference_01*;

are given in rows 4–6 respectively. Finally, all the top-level instances are brought together in an ABB system assembly in row 7.

ABB object types such as *Isotropic Material Model* and *Block* are reused multiple times in this simple example because all four continuum bodies use isotropic materials and their shapes are blocks. Reusability can be carried down to the instance level in the case of standard library-type instances such as material model instances. The right side of Fig. 4 shows the FEA SMM automatically produced for this ABB system.

6. Closure

In this paper, we present an ABB information representation for solid mechanics and thermal systems. Specific ABB models of this type are usually solved using FEA modeling. The MRA architecture that ABBs rely on for such solutions was illustrated in Fig. 1. Then the information architecture of ABBs for solid mechanics and thermal systems was developed and illustrated in Fig. 2. Based on this information architecture, an EXPRESS-G diagram, Fig. 3, was presented to describe the information attributes and hierarchy which are implemented as constrained objects (COBs). With an electronics package case study, we demonstrated that the ABB model is capable of representing product-independent analysis concepts as semantically rich, reusable, modular, and tool-independent objects.

Future publications are anticipated which will describe how ABB systems are transformed into FEA models as in Fig. 4. Such transformations include vendor-specific binding, automated pre-preprocessing (e.g. body decomposition via chopping) and post-postprocessing. Experience to date indicates that this approach provides better knowledge capture and increased automation versus traditional direct FEA modeling.

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