**The Industrial Kitting Ontology Version 1.0**

**Author List**

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# Overview

The purpose of this paper is to document the contents of the industrial kitting ontology being developed at the National Institute of Standards and Technology (NIST) as part of the Knowledge-Driven Robot Planning (KDRP) project[[1]](#footnote-1) in the Next Generation Robotics and Automation program[[2]](#footnote-2). This ontology will also serve as the basis for the Industrial Robotics Ontology as part of the IEEE Robotics and Automation Society’s (RAS) Ontologies for Robotics and Automation (ORA) Standard Working Group[[3]](#footnote-3).

The goal of the KDRP project is to develop the measurement science and standards to enable advancements in the autonomous decision-making of robots through application to specific scenarios relevant to manufacturing. The ability to create and execute plans in real-world scenarios is what separates a machine-tool from an intelligent manufacturing system. Plans enable a robot to change its actions to deal with uncertainty in its environment and to rapidly switch to new tasks. These plans are based on models of the current environment, predictions about the future, and a priori knowledge of causal relationships between current actions and results. The breadth and usability of knowledge in these models is one of the main factors that constrains the flexibility and performance of manufacturing planning systems. Currently, however, there is no accepted standardized way to represent this knowledge, to reason with this knowledge, or to measure the performance of these systems. The goal of the industrial kitting ontology is to provide this standard knowledge representation.

The industrial kitting objects ontology is written in Web Ontology Language (OWL) [[1](#_ENREF_1)]. Conceptually, the model is an object model in which there are classes with attributes (but no functions, constructors, etc.). OWL has classes but does not have attributes; it has ObjectProperties and DataProperties instead. They may be used to model attributes. OWL Properties are global, not local to a class, so localizing each attribute to a class is done by a naming convention that includes the class name and the attribute name. OWL supports multiple inheritance, but that has not been used in the kitting ontology. Except by subclass relationship, no object is in more than one class.

The model has two top-level classes, SolidObject and DataThing, from which all other classes are derived. SolidObject models solid objects, things made of matter. DataThing models data. Subclasses of SolidObject and DataThing are defined as shown in Table 1. The level of indentation indicates subclassing. For example, PartsBin is derived from BoxyObject, and BoxyObject is derived from SolidObject. Items in *italics* following class are names of class attributes. Derived types inherit the attributes of the parent. Each attribute has a specific type not shown in the listing below. If an attribute type has derived types, any of the derived types may be used.

The names of the OWL properties that give the attributes shown in the table above are formed from the attribute name by adding the prefix *has*class*\_* where class is the class name. For example, the name of the ObjectProperty for the *SolidObjects* attribute of a WorkTable is hasWorkTable\_SolidObjects.

Many of the ObjectProperties in the kitting ontology have inverses. The names of the inverse object properties are formed by changing the *has* at the beginning of the name to *hadBy* and reversing the order of the other two components of the name. For example, the inverse of hasKit\_Parts is hadByPart\_Kit. The fact that two ObjectProperties are inverses is indicated by putting an InverseObjectProperties statement in the ontology.

Each SolidObject has a native coordinate system conceptually fixed to the object. The native coordinate system of a BoxyObject, for example, has its origin at the middle of the bottom of the object, its Z axis perpendicular to the bottom, and the X axis parallel to the longer horizontal edges of the object.

Table 1: Kitting Object Ontology Overview

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| **SolidObject** *PrimaryLocation SecondaryLocation* |
| **BoxyObject** *Length Width Height* |
| **WorkTable** *SolidObjects* |
| **EndEffector** *Description Weight Id LoadWeight* |
| **GripperEffector** |
| **VacuumEffector** *CupDiameter Length* |
| **VacuumEffectorMultiCup** *ArrayNumber ArrayRadius* |
| **VacuumEffectorSingleCup** |
| **EndEffectorChangingStation** *EndEffectorHolders* |
| **EndEffectorHolder** *EndEffector* |
| **Kit**  *Tray DesignRef Parts Finished?* |
| **KittingWorkstation** *WorkTable Robot ChangingStation AngleUnit LengthUnit  WeightUnit KitDesigns OtherObstacles Skus* |
| **KitTray** *SkuRef SerialNumber* |
| **LargeBoxWithEmptyKitTrays**  *LargeContainer Trays* |
| **LargeBoxWithKits** *LargeContainer Kits KitDesignRef Capacity* |
| **LargeContainer** *SkuRef SerialNumber* |
| **Part** *SkuRef SerialNumber* |
| **PartsBin**  *PartQuantity PartSkuRef SkuRef SerialNumber* |
| **PartsTray** *SkuRef SerialNumber* |
| **PartsTrayWithParts** *PartTray* |
| **Robot** *Description MaximumLoadWeight EndEffector WorkVolume* |
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| **DataThing** |
| **BoxVolume** *MaximumPoint MinimumPoint* |
| **KitDesign** *KItTraySkuRef PartRefAndPoses* |
| **PartRefAndPose** *SkuRef Point XAxis ZAxis* |
| **PhysicalLocation** *RefObject* |
| **PoseLocation** *Point ZAxis XAxis* |
| **PoseLocationIn** |
| **PoseLocationOn** |
| **PoseOnlyLocation** |
| **RelativeLocation** *Description* |
| **RelativeLocationIn** |
| **RelativeLocationOn** |
| **Point** *X Y Z* |
| **ShapeDesign** *Description* |
| **BoxyShape** *Length Width Height HasTop* |
| **StockKeepingUnit** *Description Shape Weight EndEffectorRefs* |
| **Vector** *I J K* |

Each SolidObject A has at least one PhysicalLocation (the *PrimaryLocation*). A PhysicalLocation is defined by giving a reference SolidObject B and information saying how the position of A is related to B. Two types of location are required for operation of the kitting workstation. Relative locations, specifically the knowledge that one SolidObject is in or on another, are needed to support making logical plans for building kits. Mathematically precise locations are needed to support robot motion. The mathematical location, PoseLocation, gives the pose of the coordinate system of A in the coordinate system of B. The mathematical information consists of the location of the origin of A’s coordinate system and the directions of its Z and X axes. The mathematical location variety has subclasses representing that, in addition, A is in B (PoseLocationIn) or on B (PoseLocationOn). The subclasses of RelativeLocation are needed not only for logical planning, but also for cases when the relative location is known, but the mathematical information is not available. This occurs, for example when a PartsBin is being used, since by definition, the Parts in a PartsBin are located randomly.

All chains of location from SolidObjects to reference SolidObjects must end at a KittingWorkstation (which is the only class of SolidObject allowed to be located relative to itself).

For planning, it is assumed that SolidObjects do not move unless a command moves them. Also, if SolidObject A is in or on SolidObject B (so that the reference object for A is B), then if B is moved, the position of A relative to B is unchanged.

A SolidObject may be given multiple locations by using its *SecondaryLocation* attribute. If multiple locations are used, they are expected to be logically and mathematically consistent.

The kitting ontology includes several subclasses of SolidObject that are formed from components that are SolidObjects. These are: Kit, PartsTrayWithParts, LargeBoxWithEmptyKitTrays, and LargeBoxWithKits. Combined objects may come into existence or go out of existence dynamically when a kitting workstation is operating. For example, when all the parts in a PartsTrayWithParts have been removed and put into kits, the PartsTrayWithParts should go out of existence and the PartsTray that was holding Parts should have its location switched from its location relative to the PartsTrayWithParts to the former location of the PartsTrayWithParts.

In the current version of the kitting ontology, there are two ways in which the shape of a SolidObject can be specified. First, if the SolidObject is a BoxyObject, it is shaped like a box with length, width, and height. A WorkTable gets its shape that way. Second, if the SolidObject has a SkuRef, its shape is the shape specified in the referenced StockKeepingUnit. That shape is given by a ShapeDesign, which is an abstract class that does not have any attributes that describe shape. Currently, there is one derived class of ShapeDesign, named BoxyShape. A BoxyShape is a box with Length, Width, and Height. A BoxyShape may or may not have a top, as specified by the boolean HasTop attribute. These two methods of describing shape are adequate for making kits of boxes, but are not adequate for most industrial forms of kitting. For manipulating non-boxy SolidObjects some mathematically usable representation of shape will be required. The most commonly used type of shape representation is the boundary representation. Boundary representations are too complex to be modeled in OWL, so either some interface from OWL to a boundary representation will need to be constructed, or a simpler but usable shape representation will need to be defined and modeled in OWL.

# Kitting ontology details

In this section we will take a deeper look at the structure of each portion of the ontology. All of the objects listed below are types of SolidObjects, which is an abstract class not intended to be instantiated.

The main portions of the ontology include:

* Kitting Workstation (Figure 1)
* Changing Station (Figure 2)
* Large Box With Empty Kit Trays (Figure 3)
* Large Box With Kits (Figure 4)
* Parts Tray With Parts (Figure 5)
* Robot (Figure 6)
* Stock Keeping Unit (SKU) (Figure 7)
* Work Table (Figure 8)

The structure of the kitting workstation class is shown in Figure 1. The figure shows the names of the attributes of a kitting workstation. The first two attributes (PrimaryLocation and SecondaryLocation) are inherited from the SolidObject class. The rest of the attributes are specific to the kitting workstation class. The AngleUnit, LengthUnit, and WeightUnit apply to all quantities in a data file that are in terms of those unit types. No other unit types are used in the model.

In Figures 1-8 (which were generated by XMLSpy[[4]](#footnote-4) from XML schemas), a dotted line around a box means the attribute is optional (may occur zero times), while a *0..∞* underneath a box means it may occur more than once, with no upper limit on the number of occurrences.

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| Figure 1: Kitting Workstation Model |

Figure 2 through Figure 8 follow the same structure as what is shown in Figure 1.

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| Figure 2: Changing Station Model |

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| Figure 3: Large Box With Empty Kit Trays Model |

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| Figure 4: Large Box With Kits Model |

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| Figure 5: Parts Tray With Parts Model |

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| Figure 6: Robot Model |

The robot model is simple and does not currently have any kinematics or even any shape for the robot. It is likely that additional attributes will be added in the future.

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| Figure 7: Stock Keeping Unit Model |

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| Figure 8: Work Table Model |

# Kitting ontology details

In this section, we provide paragraph descriptions of each of the classes in the kitting ontology, in alphabetical order.

* **Box Volume** - A BoxVolume is a DataThing. A BoxVolume has a maximum point (hasBoxVolume\_MaximumPoint) and a minimum point (hasBoxVolume\_MinimumPoint). These are diagonally opposite corner points of a box shaped volume whose edges are aligned with the coordinate system in which the BoxVolume is located. The minimum point has the minimum values of X, Y, and Z. The maximum point has the maximum values of X, Y, and Z.
* **Boxy Object** - A BoxyObject is a SolidObject. A BoxyObject is box shaped. It has length, width, and height (hasBox\_Length, hasBox\_Width, hasBox\_Height). It has a preferred partial orientation in which the edges along which the height is measured are vertical (parallel to the force of gravity). The length is larger of the two dimensions that are not the height. The width is smaller of the two dimensions that are not the height. The coordinate system of a BoxyObject (i.e. the thing that is located and oriented by a pose) has its origin in the middle of the bottom, its Z-axis parallel to the height sides, and its X-axis parallel to to the length sides. Since this still allows two choices for orientation (four if the length and width are equal) which may or may not be distinguishable, some subtypes of BoxyObject will need one more piece of orientation information.
* **Boxy Shape** - A BoxyShape is a ShapeDesign. A BoxyShape is box shaped. It has length, width, height, and a boolean indicator or whether it has a top (hasBoxyShape\_Length, hasBoxyShape\_Width, hasBoxyShape\_Height, hasBoxyShape\_hasTop). It has a preferred partial orientation in which the edges along which the height is measured are vertical (parallel to the force of gravity). The length is larger of the two dimensions that are not the height. The width is smaller of the two dimensions that are not the height. The coordinate system of a BoxyShape (i.e. the thing that is located and oriented by a pose) has its origin in the middle of the bottom, its Z-axis parallel to the height sides, and its X-axis parallel to to the length sides.
* **Data Thing** - A Data Thing is a Thing. A DataThing includes all complex data types such as Vector, PhysicalLocation, etc. Currently, it has no properties.
* **End Effector** - An EndEffector is a SolidObject. It is an end effector for a robot. An EndEffector has a description (hasEndEffector\_Description), a weight (hasEndEffector\_Weight), and a maximum weight it can lift (hasEffector\_MaximumLoadWeight). Every EndEffector is either a GripperEffector or a VacuumEffector. Every EndEffector in a KittingWorkstation is either attached to the end of a robot arm (hadByEndEffector\_Robot) or sitting in an EndEffectorHolder (hadByEndEffector\_EndEffectorHolder) at an EndEffectorChangingStation. An EndEffector must not be holding anything when it is placed in an EndEffectorHolder or when it is sitting in an EndEffectorHolder.
* **End Effector Changing Station** - An EndEffectorChangingStation is a SolidObject. It is a place where end effectors are stored and where the robot can change end effectors. It has EndEffectorHolders (hasChangingStation\_EndEffectorHolders). An EndEffectorChangingStation belongs to a KittingWorkstation (hadByChangingStation\_Workstation).
* **End Effector Holder** - An EndEffectorHolder is a SolidObject. An EndEffectorHolder holds zero or one EndEffector (hasEndEffectorHolder\_EndEffector). An EndEffectorHolder is part of an EndEffectorChangingStation (hadByEndEffectorHolder\_ChangingStation).
* **Gripper Effector** - A GripperEffector is an EndEffector. A GripperEffector holds an object by gripping it with fingers or claws.
* **Kit** - A Kit is a SolidObject. A Kit has a KitDesign (hasKit\_Design), a KitTray (hasKit\_Tray), a set of Parts (hasKit\_Parts), and a boolean indicator of whether the Kit is finished (isKit\_Finished). The coordinate system of a Kit is in the same place as the coordinate system of its KitTray. The PrimaryLocation of a Part in a Kit should be given by a PoseLocationIn that is relative to the KitTray. A Kit may belong to a LargeBoxWithKits (hadByKit\_LargeBoxWithKits).
* **Kit Design** - A KitDesign is a DataThing. A KitDesign identifies a type of tray (hasKitDesign\_KitTraySku), and intended poses of parts in finished kits of this design (hasKitDesign\_PartRefAndPoses). The pose (Point, zAxis, and xAxis) in a PartRefAndPose specifies the location of the part relative to the coordinate system of the ShapeDesign of the tray. Each KitDesign belongs to a KittingWorkstation (hadByKitDesign\_Workstation).
* **Kit Tray** - A KitTray is a BoxyObject. A KitTray is designed to hold Parts with various SKU ids in known positions. A KitTray has a SKU (hasKitTray\_Sku) and a serial number (hasKitTray\_SerialNumber). A KitTray may belong to a Kit (hadByKitTray\_Kit) or to a LargeBoxWithEmptyKitTrays (hadByKitTray\_LargeBoxWithEmptyKitTrays).
* **Kitting Workstation** - A KittingWorkstation is a SolidObject. A KittingWorkstation contains a work table (hasWorkstation\_WorkTable), a robot (hasWorkstation\_Robot), an EndEffectorChangingStation (hasWorkstation\_ChangingStation), and other fixed obstacles (hasWorkstation\_OtherObstacles) such as a computer. A KittingWorkstation has an angle unit (hasWorkstation\_AngleUnit), a length unit (hasWorkstation\_LengthUnit) and a weight unit (hasWorkstation\_WeightUnit). All angle, length, and weight values related to the workstation must use those units. A KittingWorkstation has StockKeepingUnits it knows about (hasWorkstation\_Skus). A KittingWorkstation has KitDesigns it knows about (hasWorkstation\_KitDesigns). In addition, containers of various sorts enter and leave the workstation. The robot builds kits of parts by executing kitting plans as directed by a kitting plan execution system. The location of each instance of KittingWorkstation should be given relative to itself in order to end the chain of relative locations.
* **Large Box With Empty Kit Trays** - A LargeBoxWithEmptyKitTrays is a SolidObject. A LargeBoxWithEmptyKitTrays has a LargeContainer (hasLargeBoxWithEmptyKitTrays\_LargeContainer) and a set of KitTrays which should be empty (hasLargeBoxWithEmptyKitTrays\_KitTrays). The coordinate system of a LargeBoxWithEmptyKitTrays is in the same place as the coordinate system of its LargeContainer. The PrimaryLocation of a KitTray in a LargeBoxWithEmptyKitTrays should be given by a PoseLocationIn or RelativeLocationIn that is relative to the LargeContainer. The KitTrays in a LargeBoxWithEmptyKitTrays are intended to all be of the same SKU, although there is currently no formal requirement for that.
* **Large Box With Kits** - A LargeBoxWithKits is a SolidObject. A LargeBoxWithKits has a LargeContainer (hasLargeBoxWithKits\_LargeContainer), a set of Kits (hasLargeBoxWithKits\_Kits), a KitDesign (hasLargeBoxWithKits\_KitDesign), and a positiveInteger giving the maximum number of kits of the given design that can be held in the box (hasLargeBoxWithKits\_Capacity). The coordinate system of a LargeBoxWithKits is in the same place as the coordinate system of its LargeContainer. The PrimaryLocation of a Kit in a LargeBoxWithKits should be given by a PoseLocationIn or RelativeLocationIn that is relative to the LargeContainer. The Kits in a LargeBoxWithKits are intended to all be of the given design, but there is currently no formal constraint requiring that.
* **Large Container** - A LargeContainer is a SolidObject. A LargeContainer can hold one or more instances of a single type of tray or bin. The single type may be a (1) KitTray, (2) PartsBin, (3) PartsTray, or (4) Kit. A LargeContainer has a SKU (hasLargeContainer\_Sku) and a serial number (hasLargeContainer\_SerialNumber). A LargeContainer may belong to a LargeBoxWithEmptyKitTrays (hadByLargeContainer\_LargeBoxWithEmptyKitTrays) or to a LargeBoxWithKits (hadByLargeContainer\_LargeBoxWithKits).
* **Part** - A Part is a SolidObject. It has a StockKeepingUnit (hasPart\_Sku and a SerialNumber (hasPart\_SerialNumber). A Part may belong to a Kit (hadByPart\_Kit) or to a PartsTrayWithParts (hadByPart\_PartsTrayWithParts).
* **Part Reference And Pose** - A PartRefAndPose is a DataThing. A PartRefAndPose identifies a type of part by giving its SKU (hasPartRefAndPose\_Sku), it specifies the location of the part (hasPartRefAndPose\_Point), and the orientation of the Part (hasPartRefAndPose\_XAxis and hasPartRefAndPose\_ZAxis). The pose is relative to the coordinate system of the KitTray identified in the KitDesign. A PartRefAndPose belongs to a KitDesign (hadByPartRefAndPose\_KitDesign).
* **Parts Bin** - A PartsBin is a SolidObject used to hold Parts in unknown positions. A PartsBin has a SKU (hasPartsBin\_Sku), a serial number (hasPartsBin\_SerialNumber), the name of the SKU for the parts it contains (hasPartsBin\_SkuRef), and the number of parts it holds (hasPartsBin\_PartQuantity).
* **Parts Tray** - A PartsTray is a SolidObject used to hold Parts. A PartsTray has a SKU (hasPartsTray\_Sku) and a serial number (hasPartsTray\_SerialNumber). A PartsTray may belong to a PartsTrayWithParts (hadByPartsTray\_PartsTrayWithParts).
* **Part Tray With Parts** - A PartsTrayWithParts is a SolidObject. A PartsTrayWithParts has a PartsTray (hasPartsTrayWithParts\_Tray) and a set of Parts (hasPartsTrayWithParts\_Parts). The coordinate system of a PartsTrayWithParts is in the same place as the coordinate system of its PartsTray. The PrimaryLocation of a Part in a PartsTrayWithParts should be given by a PoseLocationIn that is relative to the PartsTray. The Parts in a PartsTrayWithParts are intended to all be of the same SKU, although there is currently no formal requirement for that.
* **Pose Location** - A PoseLocation is a PhysicalLocation. A PoseLocation consists of a Point (hasPoseLocation\_Point), a Vector for the Z axis (hasPoseLocation\_ZAxis), a Vector for the X axis (hasPoseLocation\_XAxis), and a reference object inherited from the PhysicalLocation class (hasPhysicalLocation\_RefObject). The data for the Point, the ZAxis and the XAxis are expressed relative to the coordinate system of the reference object. A PoseLocation must be a PoseOnlyLocation, a PoseLocationIn, or a PoseLocationOn.
* **Pose Only Location** - A PoseLocation is a PoseLocation. A PoseOnlyLocation consists of a Point (hasPoseLocation\_Point), a Vector for the Z axis (hasPoseLocation\_ZAxis), a Vector for the X axis(hasPoseLocation\_XAxis), and a reference object(hasPhysicalLocation\_RefObject) all inherited from PoseLocation. The data for the Point, the ZAxis and the XAxis are expressed relative to the coordinate system of the reference object. An object located by a PoseOnlyLocation may or may not be inside or on top of the reference object of the PoseOnlyLocation.
* **Pose Location In** - A PoseLocationIn is a PoseLocation. A PoseLocationIn consists of a Point (hasPoseLocation\_Point), a Vector for the Z axis (hasPoseLocation\_ZAxis), a Vector for the X axis (hasPoseLocation\_XAxis), and a reference object (hasPhysicalLocation\_RefObject) all inherited from PoseLocation. The data for the Point, the ZAxis and the XAxis are expressed relative to the coordinate system of the reference object. A PoseLocationIn indicates that a SolidObject that has the PoseLocationIn as the value of a hasSolidObject\_PrimaryLocation or hasSolidObject\_SecondaryLocation property is inside the SolidObject that is the reference object of the PoseLocationIn. The notion of ‘inside’ is vague and might be made more precise.
* **Pose Location On** - A PoseLocationOn is a PoseLocation. A PoseLocationOn consists of a Point (hasPoseLocation\_Point), a Vector for the Z axis (hasPoseLocation\_ZAxis), a Vector for the X axis (hasPoseLocation\_XAxis), and a reference object (hasPhysicalLocation\_RefObject) all inherited from PoseLocation. The data for the Point, the ZAxis and the XAxis are expressed relative to the coordinate system of the reference object. A PoseLocationOn indicates that a SolidObject that has the PoseLocationIn as the value of a hasSolidObject\_PrimaryLocation or hasSolidObject\_SecondaryLocation property is on top of the SolidObject that is the reference object of the PoseLocationIn. The notion of ‘on top of’ is vague and might be made more precise.
* **Physical Location** - A PhysicalLocation is a DataThing. A PhysicalLocation says where a SolidObject is. A PhysicalLocation has a reference object (hasPhysicalLocation\_RefObject). A PhysicalLocation is either a RelativeLocation or a PoseLocation.
* **Point** - A Point is a DataThing. A Point has X (hasPoint\_X), Y (hasPoint\_Y), and Z (hasPoint\_Z) Cartesian coordinates.
* **Relative Location** - A RelativeLocation is a PhysicalLocation. A RelativeLocation indicates that one solid object is on or in another solid object. A RelativeLocation must be a RelativeLocationIn or a RelativeLocationOn. A RelativeLocation has a description (hasRelativeLocation\_Description) that is a string.
* **Relative Location In** - A RelativeLocationIn is a RelativeLocation. A RelativeLocationIn indicates that a SolidObject that has the RelativeLocationIn as the value of a hasSolidObject\_PrimaryLocation or hasSolidObject\_SecondaryLocation property is inside the SolidObject that is the reference object of the RelativeLocationIn. The notion of ‘inside’ is vague and might be made more precise. A RelativeLocationIn has a description inherited from RelativeLocation (hasRelativeLocation\_Description) that is a string.
* **Relative Location On** - A RelativeLocationOn is a RelativeLocation. A RelativeLocationOn indicates that a SolidObject that has the RelativeLocationOn as the value of a hasSolidObject\_PrimaryLocation or hasSolidObject\_SecondaryLocation property is on top of the SolidObject that is the reference object of the RelativeLocationOn. The notion of ‘on top of’ is vague and might be made more precise. A RelativeLocationOn has a description inherited from RelativeLocation (hasRelativeLocation\_Description) that is a string.
* **Robot** - A Robot is a SolidObject. A Robot currently has a description (hasRobot\_Description), a work volume (hasRobot\_WorkVolume), zero or one end effector (hasRobot\_EndEffector), and a maximum load weight (hasRobot\_MaximumLoadWeight). A robot belongs to a KittingWorkstation (hadByRobot\_Workstation). The Robot ontology given here might be expanded greatly to include, for example, its kinematic description, the values of joint angles, arm lengths of variable length arms, gripper actuation (open, closed, etc.), ranges, velocities, and accelerations of each joint, etc.
* **Shape Design** - A ShapeDesign is a DataThing. A ShapeDesign has only a description (hasShapeDesign\_Description) that is an xsd:string. Currently, there is only one derived type of ShapeDesign. That is BoxyShape.
* **Solid Object** - A SolidObject is a Thing. A SolidObject has a location (hasSolidObject\_PrimaryLocation). This is a PhysicalLocation that relates the location of the object to the location of some other SolidObject. The location of a SolidObject may be on a WorkTable (hadBySolidObject\_WorkTable). No SolidObject except the Workstation may be located with respect to itself, and all chains of primary location must end at the Workstation. A SolidObject may have zero to many secondary location descriptions (hasSolidObject\_SecondaryLocation). These are also PhysicalLocations. The secondary locations are required to be logically and mathematically consistent with the value of hasSolidObject\_PrimaryLocation so that all locations of a SolidObject describe (or are consistent with) a single place in space.
* **Stock Keeping Unit** - A StockKeepingUnit is a DataThing. A StockKeepingUnit is a description of a type of object. Every StockKeepingUnit has a description (hasSku\_Description), a shape (hasSku\_Shape), that is a ShapeDesign, a weight (hasSku\_Weight), and references to the ids of EndEffectors that can handle it (hasSku\_EndEffectors). A StockKeepingUnit belongs to a KittingWorkstation (hadBySku\_Workstation).
* **Vacuum Effector** - A VacuumEffector is an EndEffector. A VacuumEffector holds an object by putting a cup against the object and applying a vacuum. A VacuumEffector is either a VacuumEffectorSingleCup or a VacuumEffectorMultiCup. A VacuumEffector has a cup diameter (hasVacuumEffector\_CupDiameter) and a length (hasVacuumEffector\_Length).
* **Vacuum Effector MultiCup** - A VacuumEffectorMultiCup is a VacuumEffector with two or more identical cups (hasMultiCup\_ArrayNumber). A VacuumEffectorMultiCup has an array radius (hasMultiCup\_ArrayRadius). The cups are arranged in a circular array spaced evenly apart. The center of the wide end of one cup is on the X-axis of the coordinate system of the VacuumEffectorMultiCup. The center of the circular array is at the origin of the coordinate system. The axis of the array circle is the Z axis of the coordinate system, and the length of the VacuumEffector is measured along that axis. The wide ends of the cups lie on the XY plane of the coordinate system.
* **Vacuum Effector Single Cup** - A VacuumEffectorSingleCup is a VacuumEffector with one cup. The center of the wide end of the cup (which is a circle) is at the origin of the coordinate system of the VacuumEffectorSingleCup. The Z axis of the coordinate system is the axis of that circle, and the length of the VacuumEffector is measured along that axis.
* **Vector** - A Vector is a DataThing. It has I (hasVector\_I), J (hasVector\_J), and K (hasVector\_K) components.
* **Work Table** - A WorkTable is a BoxyObject. The top of a WorkTable is a flat, rectangular, horizontal surface. The length and width of the top are those of the BoxyObject. A WorkTable has solid objects that are located with respect to the WorkTable, i.e. the reference object of each of those solid objects is the WorkTable (hasWorkTable\_SolidObjects). Typically, those objects will be on top of the WorkTable. This property may be deduced by finding all the objects located with respect to the WorkTable, so care will be required to keep the values of the hasWorkTable\_SolidObjects and hasPhysicalLocation\_RefObject properties consistent. A WorkTable belongs to a Workstation (hadByWorkTable\_Workstation).

# For more information

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# REFERences

[1] F. Harmelen and D. McGuiness. (2004). *OWL Web Ontology Language Overview, W3C web site:* <http://www.w3.org/TR/2004/REC-owl-features-20040210/>.

1. http://www.nist.gov/el/isd/ps/intellplanmodautosys.cfm [↑](#footnote-ref-1)
2. http://www.nist.gov/el/isd/ps/nextgenrobauto.cfm [↑](#footnote-ref-2)
3. http://lissi.fr/ora/doku.php [↑](#footnote-ref-3)
4. Certain commercial/open source software and tools are identified in this paper in order to explain our research. Such identification does not imply

   recommendation or endorsement by the authors, nor does it imply that the software tools identified are necessarily the best available for the purpose. [↑](#footnote-ref-4)