Manipulation Process Descriptions

1. Parallel Jaw Grasp
   1. Brief summary: We will tabulate a set of valid grasp orientations/positions relative to the object (i.e. grasp poses). To perform a grasp, then hand will attempt to move itself into a valid grasp pose without colliding into the shelf or the object. The hand will then close until it is exerting predetermined grasping force on the object.
   2. Execution Criterion: For the robot to execute grasping, there must exist a valid grasp pose that does not violate any collision constraints
   3. Information requirements: Pose and position of the object, object ID, shelf pose and position. The algorithm will need to determine the relative grasp pose, as well as the optimal grasp position.
2. Suction Down
   1. Brief summary: The hand will orient itself so that the suction cup is facing downwards. The hand will then position itself so that the suction cup is directly above the object it wants to pick up. Ideally, the suction cup will be directly above the center of mass of the object, though this may not always be possible). The hand will move downwards until the suction cup is flush with the object. Right now, we are unsure whether or not we will use force feedback or vision to determine how far the hand must move downwards. The suction system will then turn on. The robot will then wait a predetermined amount of time until suction is achieved. The hand will then move upwards, lifting the object.
   2. Execution Criterion: For the robot to execute downwards suction, the object must have a flat, exposed surface, with a near vertical surface normal. The hand must also be able to fit between the top of the object and the ceiling of the shelf bin.
   3. Information requirements: Pose and position of the object, object ID, shelf pose and position. The algorithm will need to determine which face to apply suction to, as well as the optimal location of the suction cup.
3. Suction Side
   1. Brief Summary: The hand will orient itself so that the suction cup plane and the attach face of the object are parallel. The hand will the position itself so that the suction cup normal is point towards the desired attachment point. The hand will then move so that the suction cup is in contact with the desired attachment point. The vacuum will then switch on. The system will then wait for a preset amount of time to guarantee that attachment has occurred.
   2. Execution Criterion: There must be a viable arm configuration that allows the suction cup to be attached to the object. The heuristic for this will probably be to determine if the attachment has is near parallel to the side walls of the bin. There also must be enough space between the attachment face and the side walls for the hand to fit in.
   3. Information requirements: Pose and position of the object, object ID, shelf pose and position. The algorithm will need to determine which face to apply suction to, as well as the optimal location of the suction cup.
4. Scoop
   1. Brief Summary: The hand will first open completely. The hand will orient itself so that the spatula finger is parallel to the ground, and the palm normal is normal to the back wall of the shelf bin. The hand will then move far enough into the bin so that the “nail” of the spatula is directly above the floor of the shelf bin. The hand will also position itself (while maintaining orientation) such that the palm normal is pointing to the horizontal center of mass of the object. The hand will then move downwards until the nail of the hand is completely flush with the floor of the shelf bin. The hand will the move towards the back wall of the shelf bin, until the tip of the nail is just at the back of the bin. At this point, the object should be scooped. The hand will then close until a predetermined amount of force is exerted on the object.
   2. Execution Criterion: The vertical dimension of the object should be smaller than the maximum gap distance between the two fingers.
   3. Information requirements: Pose and position of the object, object ID, shelf pose and position. The algorithm will need to determine where to set down the spatula, and how far back it must push the spatula to perform a scoop.
5. Topple
   1. Brief Summary: The hand will orient itself so that the spatula finger is parallel to the ground, and the palm normal is normal to the face of the object that we are going to push over. The hand will the move itself, and open/close itself so that both fingers are above the center of mass of the object. It will also position itself such that when it pushes the object, it will not rotate it about the vertical axis. The hand will then move in the direction of the palm normal until it comes into contact with the object. It will continue moving by a predetermined amount (based on the dimensions of the object), at which point the object is expected to topple.
   2. Alternate strategy: Alternatively, the hand may be oriented so that the spatula fingers are orthogonal to the ground, and the palm normal is normal to the face of the object. The hand will the move itself, and open/close itself so that both fingers are above the center of mass of the object, and both fingers will touch the object when the hand moves forward. It will also position itself such that when it pushes the object, it will not rotate it about the vertical axis. The hand will then move in the direction of the palm normal until it comes into contact with the object. It will continue moving by a predetermined amount (based on the dimensions of the object), at which point the object is expected to topple.
   3. Execution Criterion: Toppling is only possible if the object’s smallest dimension is not in the vertical direction i.e. a book lying flat on the ground cannot be toppled. The object also cannot be toppled if the maximum moment exerted on the object (about the hinging edge) through the combination of pushing with the fingers and friction on the bottom face does not exceed the moment exerted by gravity (about the hinging edge). In this case, the object would just slide instead of toppling. For instance, it is probably very difficult to topple a cube on a low friction surface. The surface normal of the pushing face of the object should also be close to parallel with the surface normal of the back face of the shelf, so that the hand can be well positioned to push the object. Otherwise, the hand will probably just rotate the object about the vertical axis. The pre-push pose of the hand must also not violate any collision constraints with the object or the shelf bin
   4. Information requirements: Pose and position of the object, object ID, shelf pose and position. The algorithm will need to determine at what height it must set the gripper, how far open/closed the fingers must be before the toppling. The algorithm must also determine how far to push the object so that it topples.
6. Push Forward
   1. Brief Summary: The hand will orient itself so that the spatula finger is parallel to the ground, and the palm normal is normal to the face of the object that we are going to push over. The hand will the move itself, and open/close itself so that both fingers are below the center of mass of the object. It will also position itself such that when it pushes the object, it will not rotate it about the vertical axis. The hand will then move in the direction of the palm normal until it comes into contact with the object. It will continue moving by the desired amount, until the object is positioned at the desired position.
   2. Alternate strategy: Alternatively, the hand may be oriented so that the spatula fingers are orthogonal to the ground, and the palm normal is normal to the face of the object. The hand will the move itself, and open/close itself so that both fingers are below the center of mass of the object, and both fingers will touch the object when the hand moves forward. It will also position itself such that when it pushes the object, it will not rotate it about the vertical axis. The hand will then move in the direction of the palm normal until it comes into contact with the object. It will continue moving by a predetermined amount (based on the dimensions of the object), at which point the object is expected to topple.
   3. Execution Criterion: Pushing is only possible if the maximum moment exerted on the object (about the hinging edge) through the combination of pushing with the fingers and friction on the bottom face does not exceed the moment exerted by gravity (about the hinging edge). This will allow the object to slide instead of toppling. It is probably easier to slide something without toppling it when pushing on a low friction surface instead of a high friction surface. The surface normal of the pushing face of the object should also be close to parallel with the surface normal of the back face of the shelf, so that the hand can be well positioned to push the object. Otherwise, the hand will probably just rotate the object about the vertical axis. The pre-push pose of the hand must also not violate any collision constraints with the object or the shelf bin
   4. Information requirements: Pose and position of the object, object ID, shelf pose and position, and the distance to push the object. The algorithm will need to determine at what height it must set the gripper, how far open/closed the fingers must be before pushing.
7. Side Push
   1. Brief Summary: The hand will orient itself so the palm normal is orthogonal to the back wall, and the bottom of the hand is parallel to the floor of the bin. The hand will position itself so that is directly to the left/right of the object that we want to push. The fingers will open/close such that at least one finger is positioned below the center of mass of the object. The hand will then move directly to the left/right until the object is in the desired position.
   2. Execution Criterion: There must be sufficient space between the hand and the side wall for the hand to fit in between. Also, see pushing criterion for push forward.
   3. Information requirements: Pose and position of the object, object ID, shelf pose and position, and the distance to push the object. The algorithm will need to determine at what height it must set the gripper, how far open/closed the fingers must be before pushing.
8. Push to Rotate
   1. Brief Summary: The hand will orient itself so that the palm normal is orthogonal to the back wall, and the bottom of the hand is parallel to the floor of the bin. The hand will position itself so that the palm normal is pointing towards the “pushing edge” of the object. The hand will then move forward until the fingers are in contact with the object. The hand will then move forward in a circular-ish motion to rotate the object.
   2. Execution Criterion: Pushing to rotate has the same execution criterion as push forward, with the addition the circular trajectory of the hand must not collide with the edge of the bin. The object must also be sufficiently in the center of the bin to allow rotation.
   3. Information requirements: Pose and position of the object, object ID, shelf pose and position. The algorithm will need to determine at what height it must set the gripper, how far open/closed the fingers must be before pushing, and the ideal final pose of the object after pushing.
9. Extract
   1. Brief Summary: The hand will remove itself from the bin (probably while grasping an object or being attached to an object via suction). The hand must remove itself in a way such that the object does not collide with the walls of the bin or the lip of the bin in the front. This probably means that the hand will try to move itself to the center of the bin, then move directly outwards.
   2. Execution Criterion: Extract is supposed to occur after any of the first 8 operations have occurred.
   3. Information requirements: Pose and positions of objects in the bin, shelf pose and position.