Playing physical 3D Tetris with robots: building mixed-case complex pallets in automated warehouses

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What does automated warehouse do?

It makes pallets of mixed products and ships them to customers.
How to build a pallet?

From rules for rigid bodies, strictly cuboid shapes:

- Every case must be confined to pallet bounding box (L,W,H)
- Every case must be supported (statically and dynamically)
- Every case must reside on (relatively) flat surface
- Stacks of cases should be periodically bridged (interlocked) by cases above
- Pallets shouldn’t have large and deep gaps between cases
Multi-criteria optimization problem: 3D Bin packing + Physics + Business rules

**Structural quality:**

- Heavier cases should be at the bottom, lighter – near the top
- Sturdier cases at the bottom, fragile at the top

**Store-friendly and regulations-compliant**

- Cases from same SPOG (aisle, departments) close together
- Same categories of product close together
- “Caustic” products (e.g. laundry detergent) below food
- Break-pack cartons on top of pallets
- Vertical segregation of different meat categories
- Special rules for promotional items
- …
What if…

- Every case in order has different dimensions $L$, $W$, $H$?
- All cases are of same dimensions?
- There are clusters of cases of similar dimensions and few of wide-ranging sizes?
- Bi-modal distribution of case sizes?
- Some cases are square, and some – very long and narrow?
- Case volumes ranging by > 10 times?
- Some cases are tall and narrow, some are very wide and flat?
- There are small heavy cases and large (and fragile) large cases?
- Cases have tapered shapes, or non-rectangular footprint, or empty tops, or nesting holes?
Layers, stacks and interlock surfaces

Interlock surface

Stack

Often interlock surfaces gets fragmented as pallet gets higher, allowing only wobbly stacks to be built near the top

Example (beverage industry)
First experience with robotic palletizing: Newburg C&S warehouse, early 2011
(software from TOPS Engineering)

Pallet quality was very poor. We needed to do something fast…
Radically new idea of palletizing algorithm:
KP composite layers (Kirill Pankratov – principal author of the algorithm)

1) Make stacks of 1-4 cases,  
   Each stack of ~ same height

2) 2-d bin packing of stacks  
   (Top view)

3) Composite KP layer:  
   Other layers can be put on top
First “KP” pallet, manually built at C&S Woburn lab, February 2011
Soon our pallets were showcase for prospective customers
Pallets examples

From Wall Street Journal video, Sept. 2017

From Walmart Brooksville go-live
Order processing and pallet-planning flowchart

1. Select SPOGs for pallet
2. Select SKUs for Layer
3. Whole order
4. Cases for one pallet
5. Stack Set 1
6. Stack Set 2
7. Stack Set 3
8. Collect stack sets
9. 2-D packing
10. Return unused cases
11. Add Layer to pallet
12. Choose best pallet
13. Add pallet to results
14. Return unused cases
15. Single pallet loop
Examples of Structured “Pattern” Layers
2D-packing of stacks of different cases

Walmart Brooksville

C&S Bethlehem
Optimizing simultaneously for structural stability and store-friendliness: example from recent customer order, color-coded by Departments
Same order, color-coded by case strength

- **Weak (fragile) cartons**
- **Strong cartons**
Beverage pallets
Meat room pallets (strict vertical segregation by category – poultry, pork, beef, etc.)
Symbotic Palletizing cell
Plan-in-Progress (PiP) branch-and-bound recursive search

Cartons in ideal sequence

PiP

PiP_1

PiP_11

PiP_12

PiP_111

PiP_121

PiP_1211

PiP_12111

Winning pallet

Final result selection

Terminated branch

X

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