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DYNAMIC SIZE 3D PACKING BASED ON FACTORY INTER-DEPARTURE TIME

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Dynamic size 3D packing based on factory inter-departure time

Abstract

One of the most important concerns in 3D printing when it scales to a factory environment is the capacity of controlling the throughput frequency to be able to achieve an optimal production of parts at the right timing in orderto maximize the profit.

In an automated factory with a fleet of 3D printers, the orders received are orchestrated in a linear sequence with several stages including the packing of the parts inside the printable volume of a build and the build scheduling, whichis queued to be printed in a device of the fleet. As the process of printing a build takes hours, once a build begins the printer won't generate any output until it finishes, thus having a low frequency of orders fulfilled leaving the factory to be delivered to the final clients.

This problem is accentuated when variations in the production arise. In the supply chain, when clients pull from the factory at a different rate, the fleet of printers is not capable of adapting its scheduling to that changes, as printing time take hours and it takes long until a batch of orders is accumulated at the output to be delivered.

This problem in printing timing also arises when there are dead periods in which there's not enough time to schedule a new build, which leads to unproductive times and lower throughput.

To solve the drawbacks associated to the low flexibility in changing the devices printing time to adapt the production to changing schedules, we have developed an algorithm that dynamically changes the 3D packing size restrictions to meet the required printing times. We use the time delta that exists between the moment that orders are packed and the moment they are printed to reorganize the buckets to meet the required packing heights.

Problem statement

In a 3D factory it is fundamental to have control over the throughput that is being produced in order to maximize the profit. On key parameter of this process is the inter-departure time, which indicates how time it takes between two orders exit the factory. In 3D printing, as printing times take long hours to finish, it is very difficult to act over this time as even with a lot of staggered printers it would be of hours.

One of the most critical knobs on this process is the number of layers in the vertical axis, as the printing time grows with this number. It depends on two parameters, the layer thickness and the height of the packed parts. The layer thickness is not so editable as it has impact on part quality, so the most flexible knob is the height, which is defined at packing time.

To have more context, a 3D packing algorithm packs all the parts inside the printable volume of a 3D printer. It may target different build parameters (e.g., packing density, orientation, zone restrictions) depending on the optimization goal (e.g., superficial quality, mechanical properties, dimensional quality, minimum time to print, maximum number ofparts in the packing, thermal optimization). As a configuration parameter, the already existing packing algorithms accept the bucket height and the parts are placed below that level.

We can use these knobs to find the right packing size configuration that helps reduce or enlarge the printing time to modulate the inter-departure time and achieve the desired throughput frequency.

State-of-the-art

Until now, the unique way to handle this issue is to manually set the packing restriction to create a quarter, half or full bucket with the orders when it is necessary. This is a labour-intensive task, so nobody does it as it is time consuming, and it is not optimal in terms of cost. The packings are generated automatically and queued to be printed, and as the needed packing height can change between the time that the packing is generated and the printing time, there are dead times and the packing becomes a kind of bottleneck for the factory scheduling, as once the packings are generated, they cannot be modified to adapt to changing production rates.

Our Contributions

In the workflow of a factory orchestration system, the objective can be the control of the throughput. Given a determined throughput that the user defines, a series of automated steps are executed from accepting the orders to packing them into a build that is scheduled to the printer. Our invention is placed between the 3D packing algorithm and the orchestration, and it transforms the factory timings to the build size restrictions that the packing algorithm accepts to generate the bucket. This conversion can be done in several ways, as with the print velocity per layer and thetiming estimation from the orchestration system we can compute the height to meet the restrictions. As printing time takes hours, this estimation can have precision of minutes without impacting the workflow.

The computed constraints related with the bucket size (e.g., quart bucket, half bucket, full bucket) are used by a 3D packings algorithm to adapt the buckets to production variations. Thus, if the orders are packed in a reduced height bucket the inter-departure time of buckets in a printer will be reduced, as the time is related with the number of layers. The printing time can also be longer when necessary by having full bucket configurations, which enlarges the time between two produced buckets.

To be able to modify the buckets that are needed, we also need to manage the buffer of packings that are queued to be printed, as they are the ones that need to meet the restrictions to be able to react in real-time, so our invention makes use of the time window between the moment in which an order of parts needs to be packed and the moment at which the build will be printed. As printing time takes hours, we can lock some of the already prepared builds and keep them waiting to be scheduled to the factory. Then we reorganize the parts in order to meet the height restrictions that we are computing based on the factory printing times provided by a factory orchestration system.

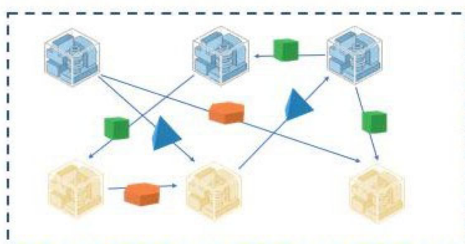

Figure 1 Reorganization of parts using the builds that are inside the time window between the packing and the printing time to meet the height restrictions to adapt to changing production printing times.

The obtained builds help to modify the printing time and the inter-departure time. This way, the orders fulfilment can be adapted and the production frequency can change based on the factory orchestration requirements. It is useful in, at least, these cases:

- Fill unproductive time gaps in the printing schedule with adapted buckets.
- Accelerate the inter-departure time with lower height buckets.
- Allow longer printing times when needed.

Our invention automatizes the generation of packings based on size restrictions taking into account real-time needs. It helps to save time and costs by generating the optimal bucket configuration that is needed at each moment based on the production throughput frequency decided by some factory orchestration system. We give the possibility to accelerate the printing time by reducing buckets size or to allow longer prints with full bucket configurations.

Experimentation examples

- **Example 1:**

In a factory, we will probably face the situation in which by either preventive or predictive maintenance we need to stop a printer at a specific moment. It is probable that, as printing take long hours, we will have a time gap before the stop time in which we can't fit the printing time for a new bucket, so it can be handled in three ways:

- Advance the stop time and continue the printing as soon as possible. It is not optimal as we do maintenance before the necessary time, wasting resources.
- Stop the printer until the planned stop time. This is not optimal as we reduce throughput.
- Start a new print and delay the maintenance time to the time it finishes. This has high risk as printing time is long, so the delay could be of hours and the printer could be damaged, which would lead to higher costs and higher unproductive times to repair it.

By using our 3D packing algorithm, it is possible to generate a bucket with size restrictions to fit in the printing time available, thus avoiding the suboptimal situations. Using the information provided by some factory devices orchestration system, we can prepare a half or quart bucket configuration with the maximum number of parts to be ableto maximize the throughput before it stops, thus reducing also unproductive time. As print times take hours, it has high impact on cost and time savings.

- **Example 2:**

We have a factory at a certain production rate, and there is the need to modulate the throughput of parts, which can be accelerated or reduced.

Let's imagine that we want to accelerate it. As printing time takes hours, the throughput is limited, and we cannot reduce the time delta at which a batch of orders gets out of the factory. It is also a common practice to put several orders inside the same bucket when it is packed, so this means that we cannot have any of those orders ready until allof them are finished, thus restricting the factory capacity to accelerate the orders readiness at the output.

By using our 3D packing algorithm, it is possible to prepare packings with bucket size restricted (e.g. half or quart bucket) that are printed in less time and will be ready faster, reducing the inter-departure time. The inverse situation can arise, and we can go back to full bucket configuration to allow longer printing times.

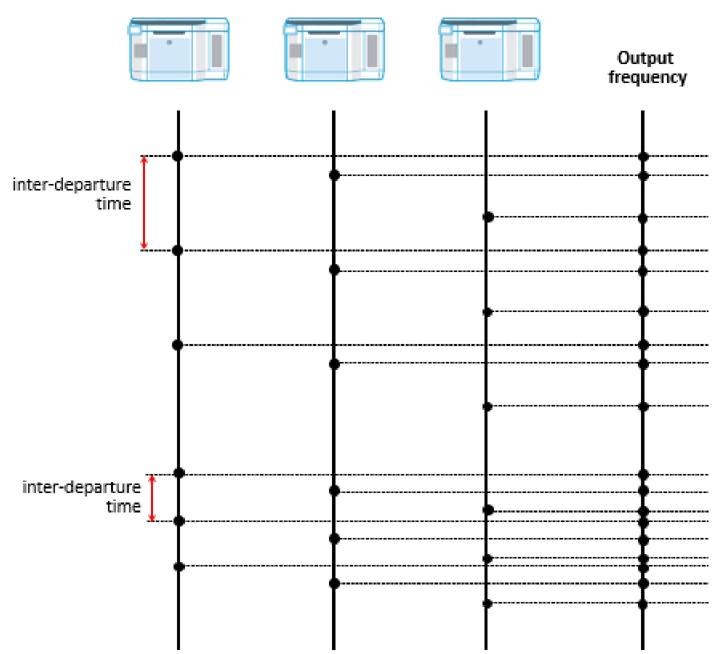

Figure 2 Change of output frequency based on inter-departure time when we modify bucket configuration at packing time.

Disclosed by Jordi Sanroma Garrit, Quim Muntal and Oriol Vendrell, HP Inc.