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SHAPING THE NEXT GENERATION OF ELECTRONICS

JUNE 23-27, 2024

MOSCONE WEST CENTER
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Efficient Automation Strategy for Package Substrate Routing

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Motivation

Background

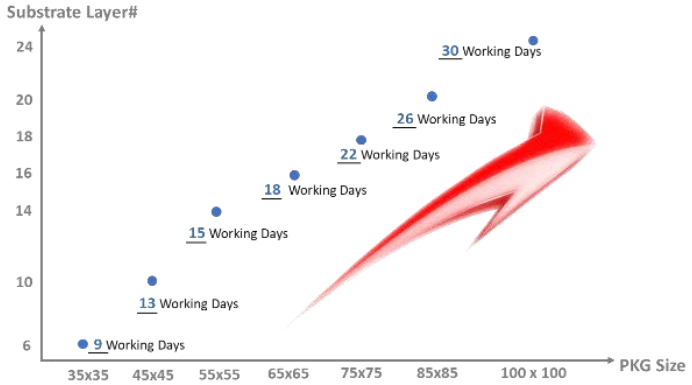
- With the imperative requirement of improving the efficiency of substrate routing design, electronic design automation (EDA) companies develop auto-routing features in packaging design tools.

Challenges

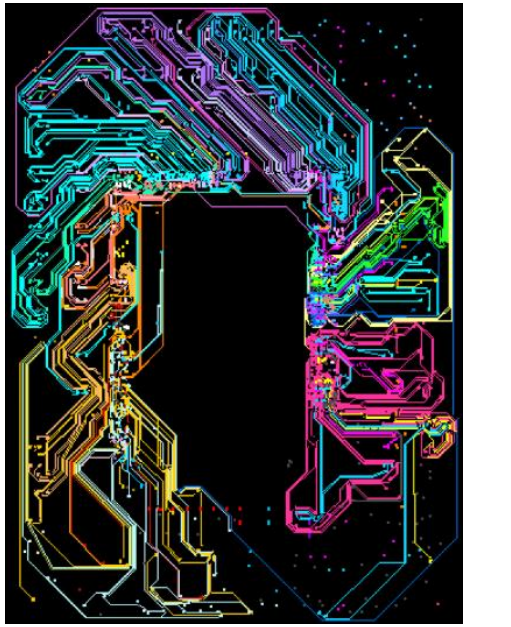
- However, some of the these traces generated by the auto routing tool are not acceptable considering the electrical performance, and even the routing completion rate is low and runtime is long in some design with complex electrical connection.

Proposal Solution

- Accordingly, we propose a die edge pin determination method implemented prior to running auto routing and a decision transformer-based routing optimization method carried out after running auto routing to enhance auto routing performance.

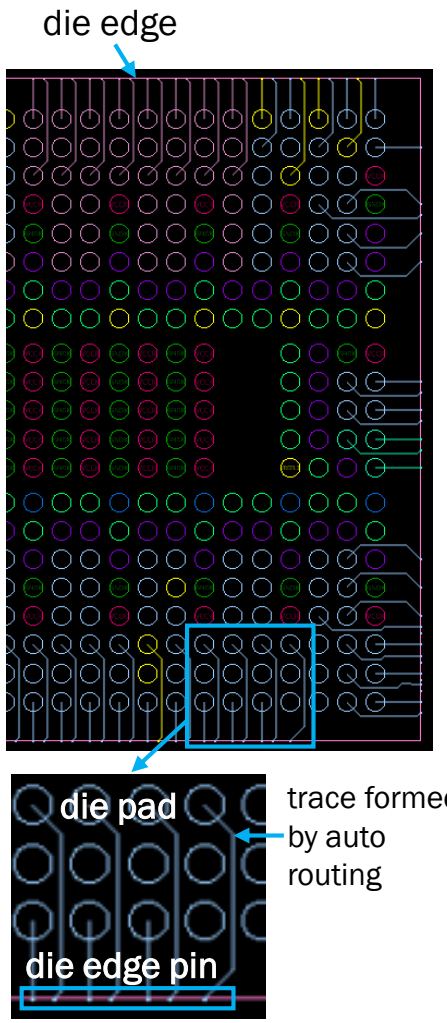


working days increase as package complexity increases.



unacceptable auto routing result.

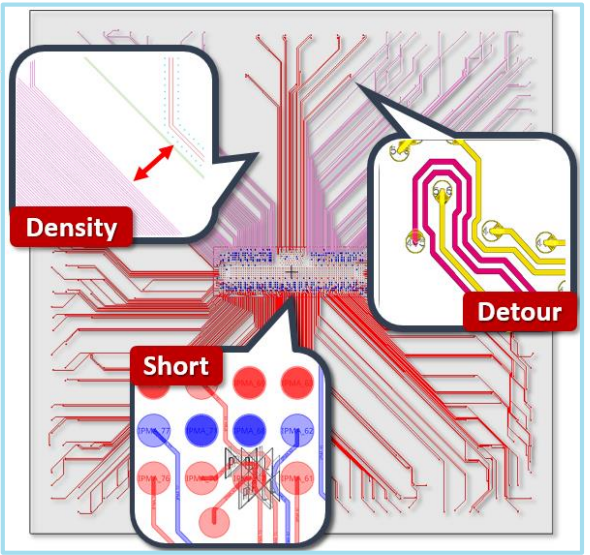
Main Idea



Process Flow

1. Assign **routing layer** for signal based on die pad location and design rules
2. Determine **die edge pin coordinate** corresponding to die pad location
   Details on Slide 4
3. Import die edge pin coordinates to design tool
4. Run **1st auto routing** to form trace connecting die edge pin and die pad
5. Import BGA symbol and place via structure on BGA
6. Run **2nd auto routing** to form trace connecting die edge pin and BGA
7. Implement **auto routing result optimization** by using AI model
   Details on Slide 6
8. Done

die edge pin



Die Edge Pin Coordinate Determination (1/3)

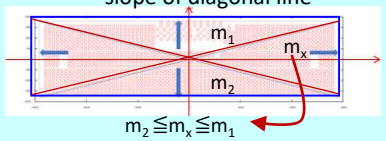
- **The process of determining the coordinate of die edge pin, which implemented by programming.**

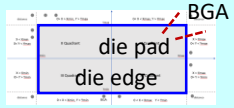
Routing Quadrant

Determine die pad's routing quadrant based on **Slope of Die Pad**

- Not Consider BGA LOC
- Consider BGA LOC

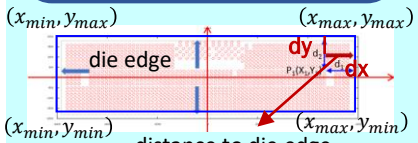
slope of diagonal line





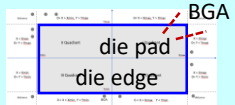
Determine die pad's routing quadrant based on **Distance to Die Edge**

- Not Consider BGA LOC
- Consider BGA LOC



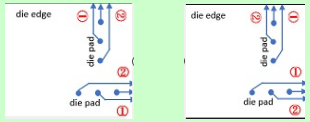
distance to die edge

$$d_x = \sqrt{(x_i - x_{max})^2}$$
$$d_y = \sqrt{(y_i - y_{max})^2}$$

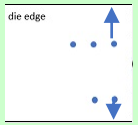


Die Edge Pin Location

Determine die pad's die edge location **Method 1**



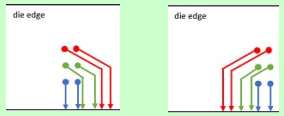
Determine die pad's die edge location **Method 2**



$$X_i = X_1 - (i-1) \times L/(N-1)$$
$$Y_i = Y_{max}$$

$$X_i = X_1 - (i-1) \times L/(N-1)$$
$$Y_i = Y_{min}$$

Determine die pad's die edge location **Method 3**

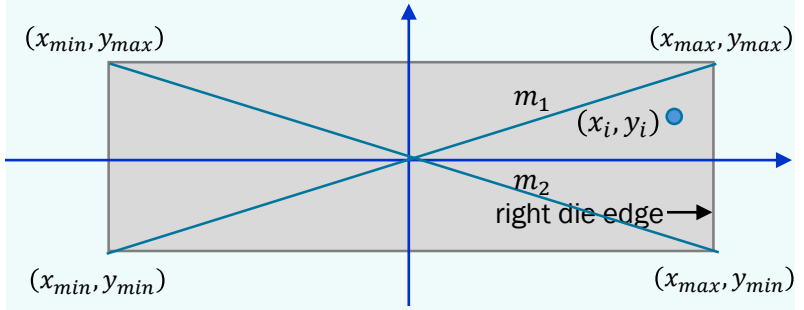


Coordinate Import

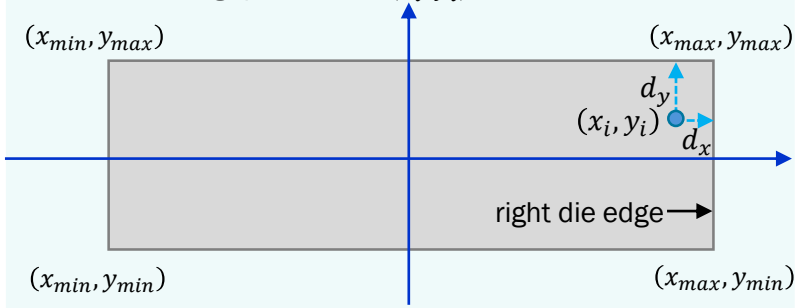
Import die edge pin coordinate file into auto routing tool

Further Details on Rerouting Quadrant

- **Methodology 1**: Routing quadrant of die pad (x_i, y_i) is determined by its **slope** (m_i). Since $x_i \geq 0$, $y_i \geq 0$ and $m_i \leq m_1$ wherein m_1 and m_2 is the slope diagonal line, right die edge is assigned as the routing quadrant of (x_i, y_i).



- **Methodology 2**: Routing quadrant of die pad (x_i, y_i) is the edge closest to it. If $d_x = \sqrt{(x_i - x_{max})^2} > \sqrt{(y_i - y_{max})^2} = d_y$, right die edge is assigned as the routing quadrant of (x_i, y_i).

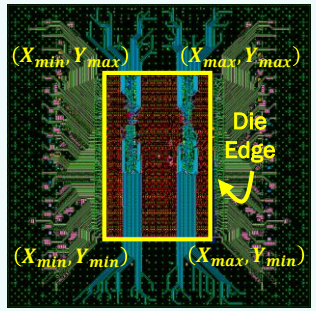


Die Edge Pin Coordinate Determination (2/3)

Further Details on Routing Quadrant

- When considering BGA location (X_{ball}, Y_{ball}) connected to the die pad, the routing quadrant is adjusted based on the rules below.
- $(X_{max}, Y_{max}), (X_{max}, Y_{min}), (X_{min}, Y_{max}), (X_{min}, Y_{min})$ are the coordinates of four die edge vertices as shown in the lower right figure.

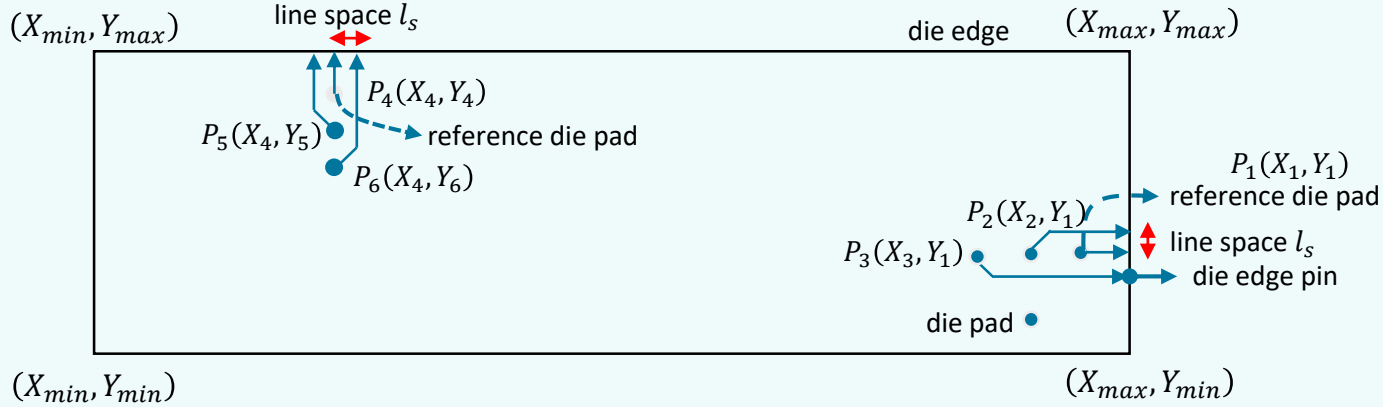
Location	Routing Quadrant
$Y_{ball} > Y_{max}$	Top die edge
$X_{ball} > X_{max}$ $Y_{max} > Y_{ball} > Y_{min}$	Right die edge
$X_{ball} < X_{min}$ $Y_{max} > Y_{ball} > Y_{min}$	Left die edge
$Y_{ball} < Y_{max}$	Bottom die edge
$X_{max} > X_{ball} > X_{min}$ $Y_{max} > Y_{ball} > Y_{min}$	NO die edge pin

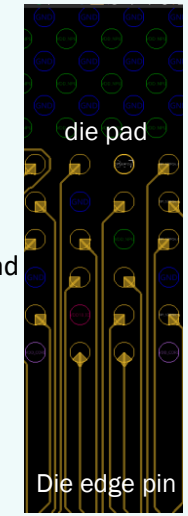


Further Details on Die Edge Pin Location

- Step 1: Determine the net order and reference die pad according to the die pad location.
- Step 2: Determine the die edge pin location based on the net order, reference die pad location and minimum line space.

- **Configuration 1**: Take $P_1(X_1, Y_1), P_2(X_2, Y_1), P_3(X_3, Y_1)$ for illustration.





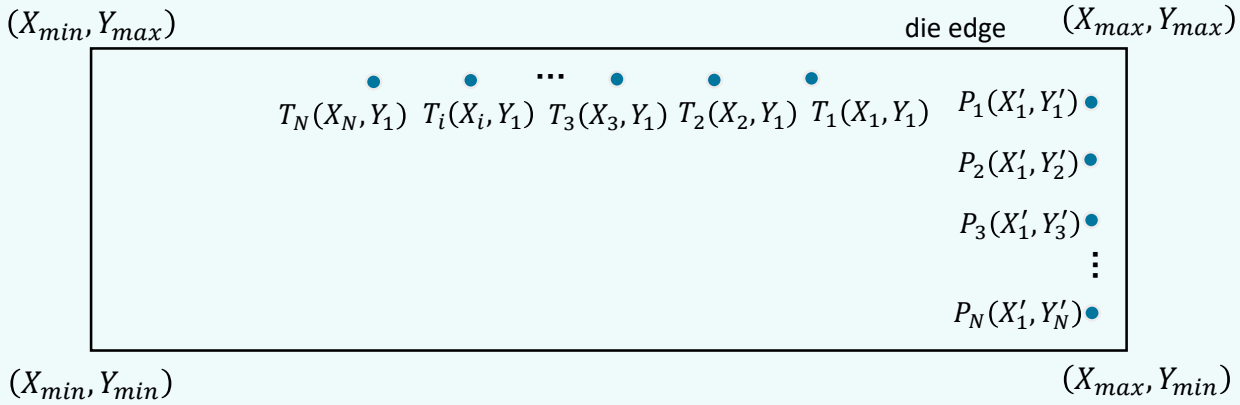
- Step 1: Since P_1 is the point closest to the right die edge, P_1 is set as the reference die pad and the net order is P_1, P_2 and then P_3.
- Step 2: The die edge pin corresponding to P_1 is (X_{max}, Y_1). Considering the line space (l_s), the die edge pin of P_2 and P_3 is $(X_{max}, Y_1 \pm l_s)$ and $(X_{max}, Y_1 \mp l_s)$ respectively.

- As stated above, for die pads P_4, P_5, P_6, P_4 is the reference die pad and the corresponding die edge pin is $(X_4, Y_{max}), (X_4 \pm l_x, Y_{max}), (X_4 \mp l_s, Y_{max})$ respectively.

Die Edge Pin Coordinate Determination (3/3)

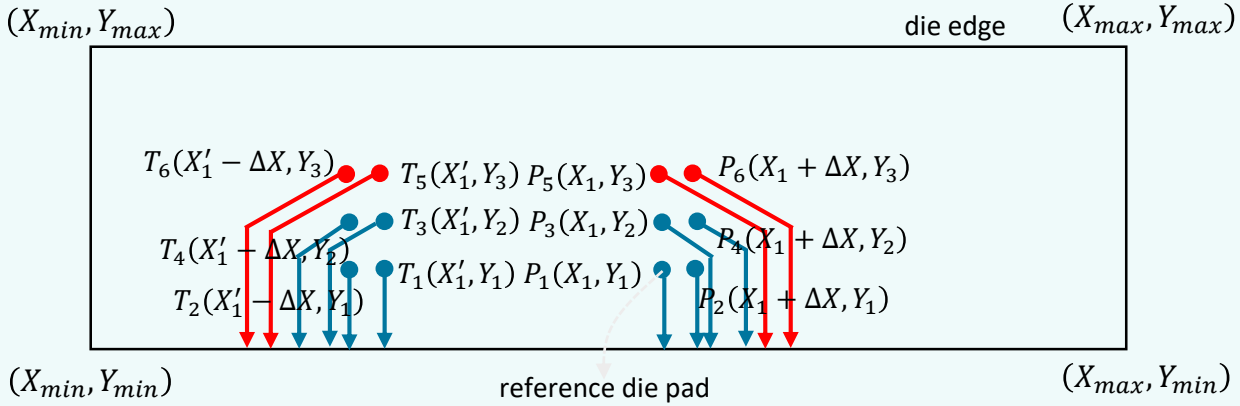
Further Details on Die Edge Pin Location

- **Configuration 2**: The die pads are disposed evenly along the die edge.

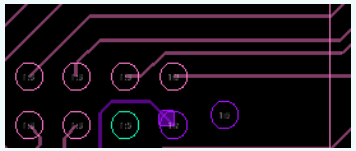


- Step 1: Since T_1 is the die pad with the smallest x-coordinate among the die pads, T_1 is set as the reference die pad and the net order is $T_1, T_2 \cdots T_N$.
- Step 2: The die edge pin corresponding to $T_i = \left(X_1 - \frac{(i-1)\times L}{N-1}, Y_{max}\right)$, wherein $L = X_1 - X_N$
- For die pads $P_1, P_2 \cdots P_i \cdots P_N, P_1$ is the reference pad and the die edge pin corresponding to $P_i = \left(X_{max}, Y_1' - \frac{(i-1)\times L}{N-1}\right)$, wherein $L = Y_1' - Y_N'$

- **Configuration 3**: The space of one side of die pad is much larger than the other.

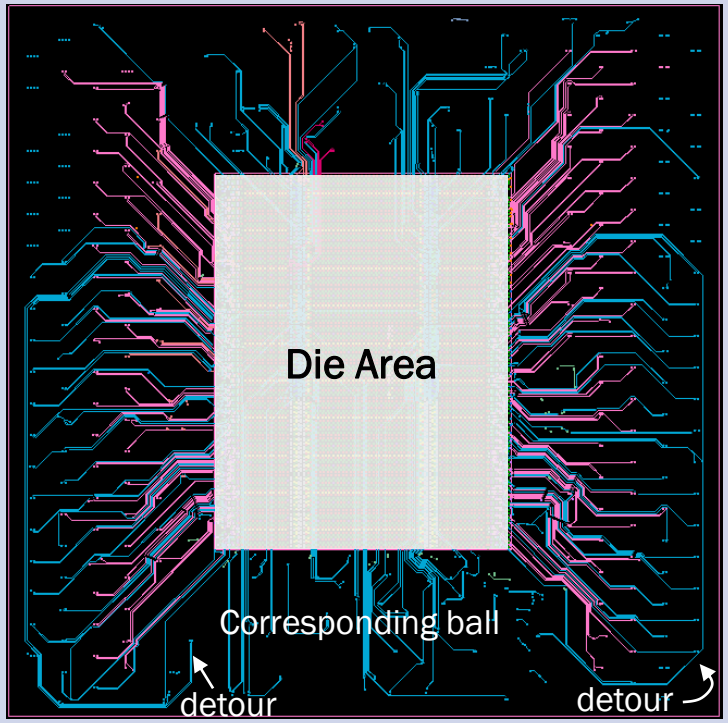


- Step 1: Since P_1 is the die pad with the smallest x-coordinate and y-coordinate among the die pads, P_1 is set as the reference die pad and the net order is $P_1, P_2, P_3, P_4, P_5, P_6$.
- Step 2: Considering the space of right side of die pad is much larger, the die edge pin corresponding to $P_i = (X_1 + (i-1)l_s, Y_{min})$, wherein l_s is the line space.
- For die pads $T_1, T_2, T_3, T_4, T_5, T_6$ with the larger space of left side, T_1 is the reference pad and the die edge pin corresponding to $T_i = (X_1' - (i -$



Evidence – Die Edge Pin Location

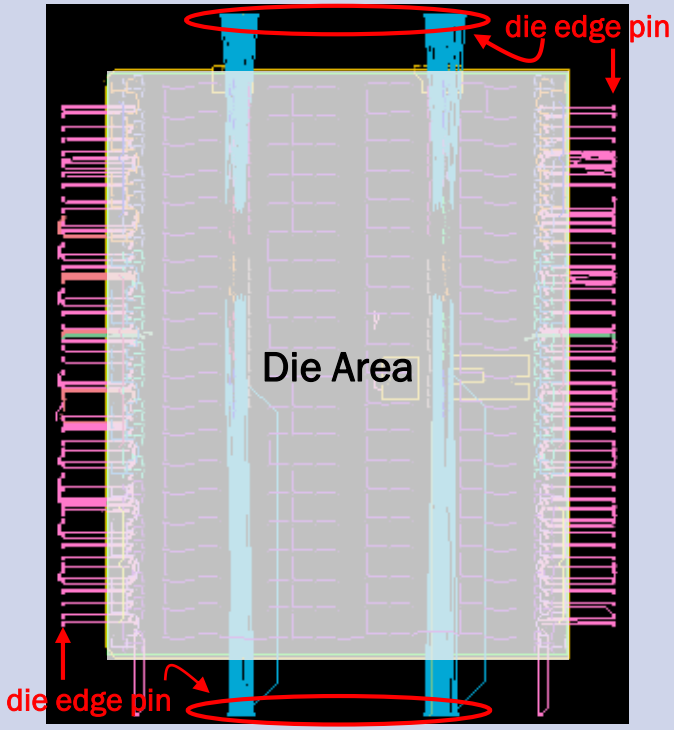
Result of Auto Routing



- Completion Rate: 83.10%
- Completion Time: 21:52:28
- Issues: Detour

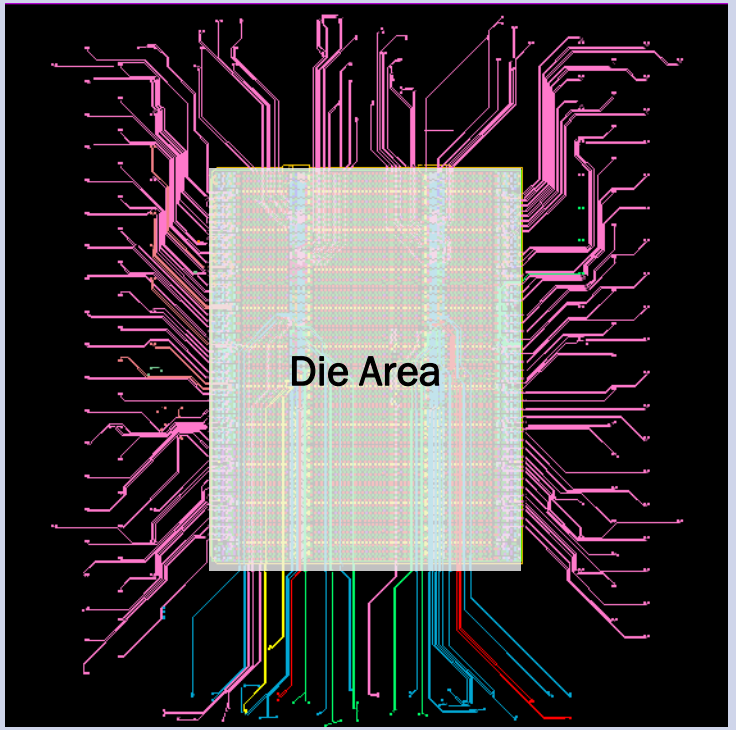
Result of Auto Routing with Die Edge Pin

1st Auto Routing Result



- Die edge pin is located based on BGA location before running 1st auto routing, which achieves better performance compared to the distance to die edge.

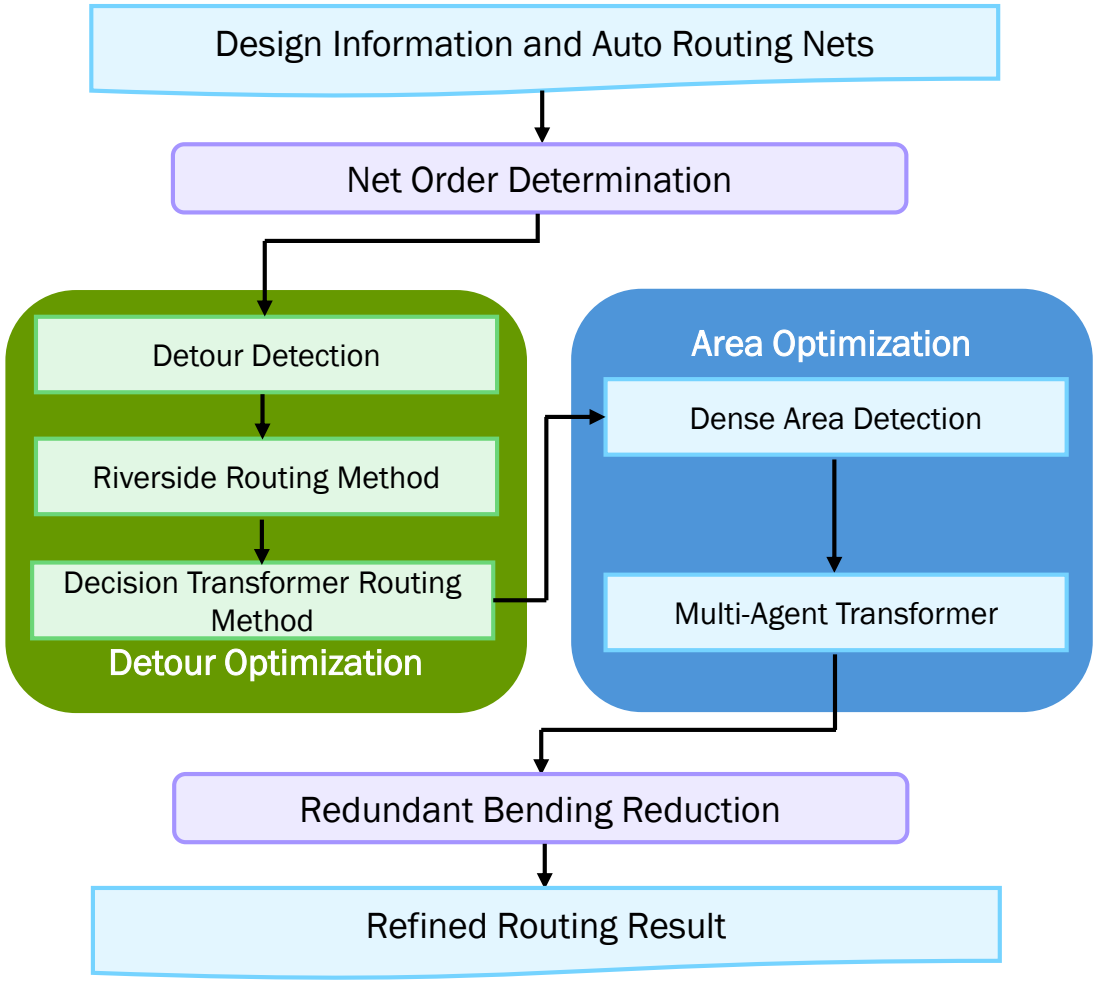
2nd Auto Routing Result



- Completion Rate: 100%
- Completion Time: 05:55:47
- Detour is eliminated.

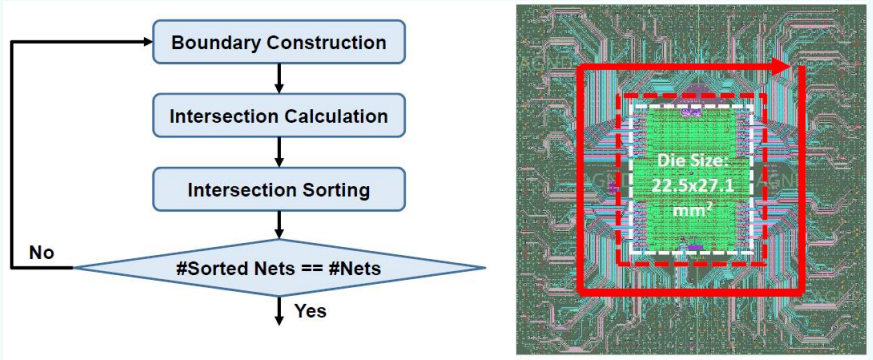
Auto Routing Result Optimization (1/2)

- The process flow of auto routing result optimization:

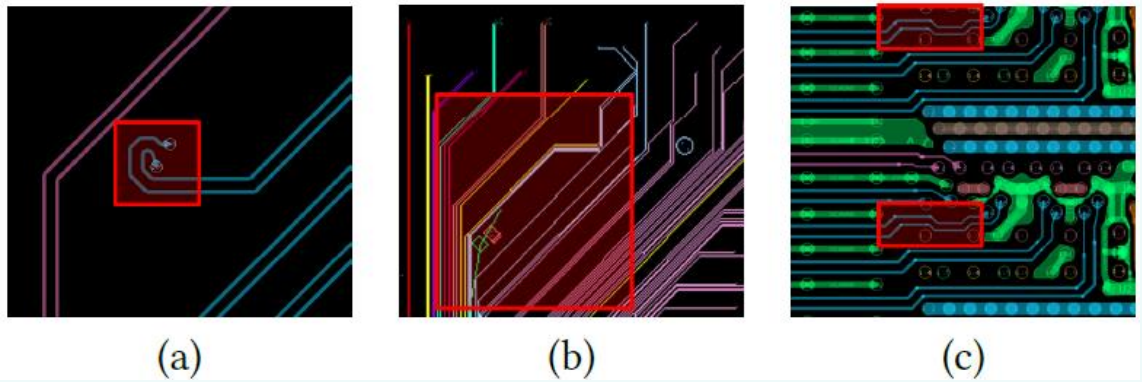


Further Details on Auto Routing Result Optimization

- Net Order Determination:



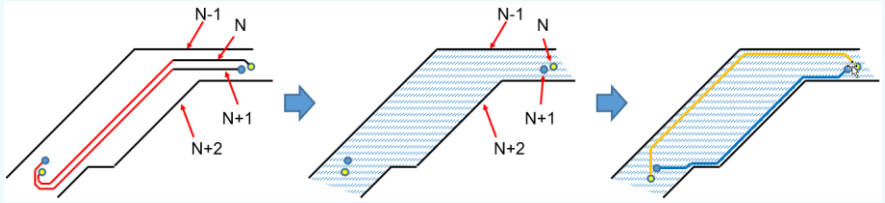
- Detour Optimization:
  - ➢ Detour Detection: CenterNet-HarNet is used as the object detection model. Different types of detours highlighted in red squares include (a) significant detours (b) slight detours within a large area (c) slight detour within a small area.



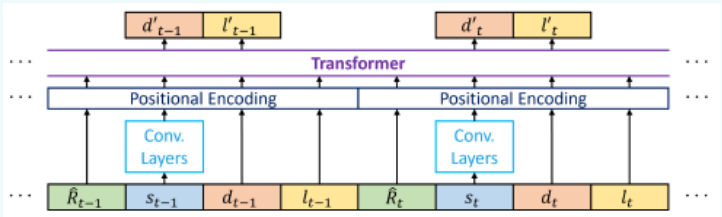
Auto Routing Result Optimization (2/2)

Further Details on Auto Routing Result Optimization

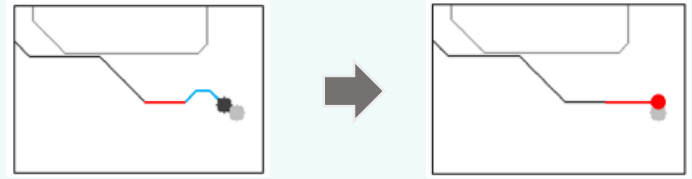
- Riverside Routing Method: the significant detours are refined by rerouting along the surrounding segments, wherein the net N is rerouted along N-1 and net N+1 is rerouted along N+2.



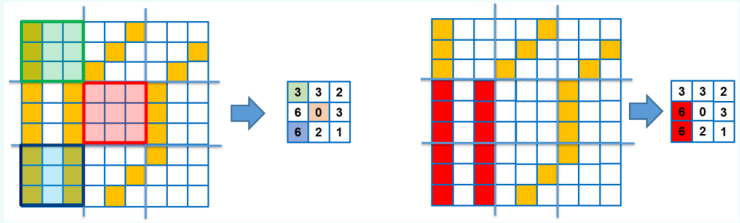
- Decision Transformer (DT) Routing Method: to address the remaining slight detours, we adopt DT as the main routing framework and treat the decision-making process as a sequence of states s, direction d, length l and returns-to-go $\widehat{R_t} = \sum_{t'=t}^{T} r_{t'}$, which is the sum of all future rewards r from the current time step t to the future time step T.



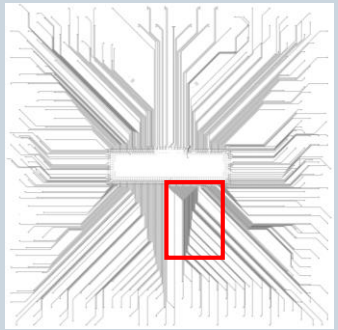
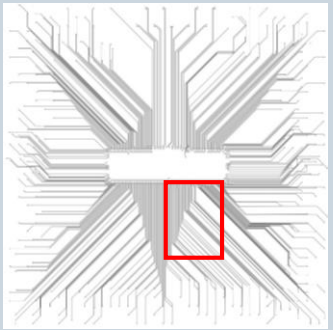
- Optimization Result of Slight Detour:



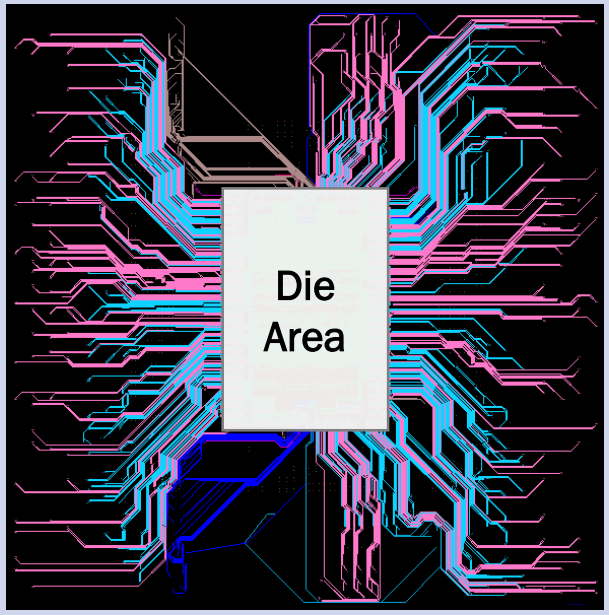
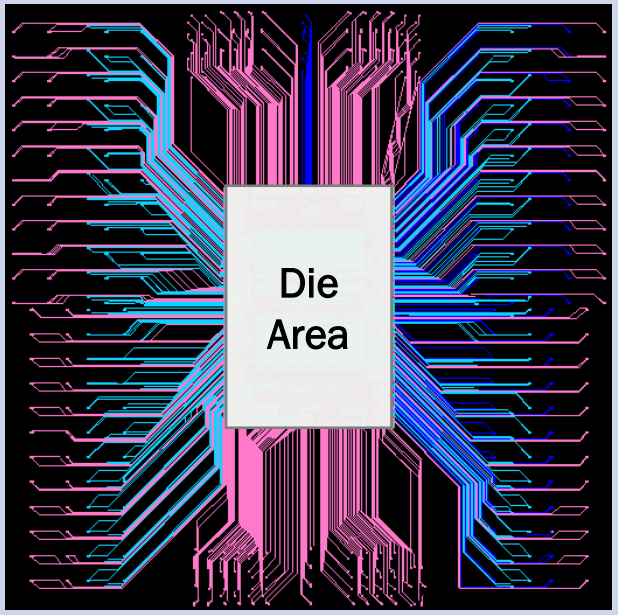
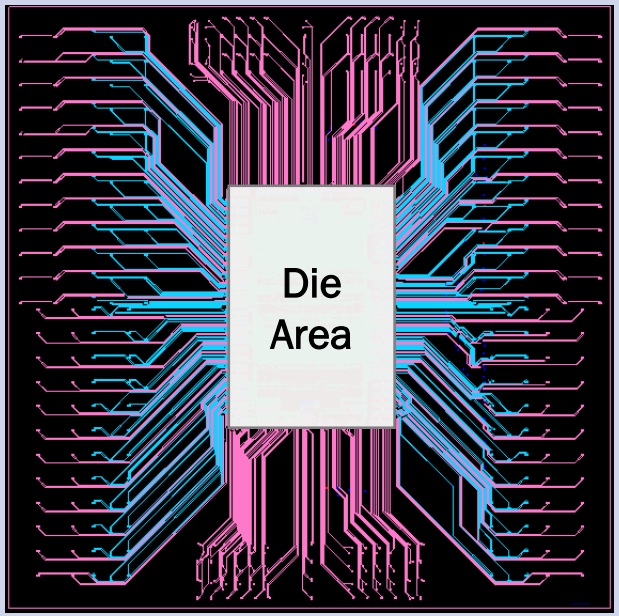
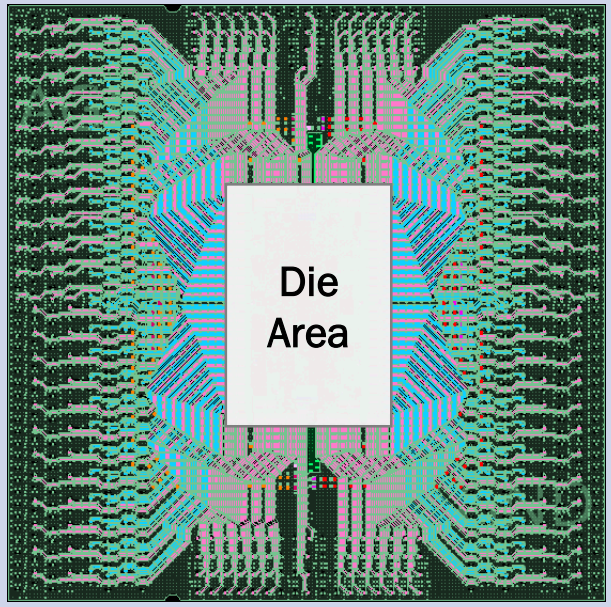
- Area Optimization:
- Dense Area Detection: The original design is divided into several routing blocks first. Each block is examined to determine if the routing resources utilized within it exceed a specific threshold, indicating a dense routing area.



- The nets identified in the dense routing area are re-routed by leveraging Multi-Agent Transformer that casts cooperative multi-agent reinforcement learning into sequence models problems.
- Optimization Result: Dense nets are rerouted evenly as shown below.

Auto Routing Result	Optimization Result
	

Evidence – AI Optimization

Auto Connect	Auto Connect + Layer Assignment + AI Optimization	Auto Connect + Layer Assignment + Die Edge Pin	Manual Routing
			
• Completion Rate = 98.90%	• Completion Rate = 99.42%	• Completion Rate = 100%	• Completion Rate = 100%
• Total time (for substrate layer -2, 4 and 6) = 17:27:21	• Optimization time(for substrate layer - 2) = 79.7 mins (688 nets)	• Total runtime (for substrate layer - 2) = 10 mins (die edge pin determination + 1st auto connect + manual optimization + 2nd auto connect)	• Total time (for substrate layer - 2) ≒ 2 working days

Summary

- The auto routing performance, including completion rate, runtime and routing quality, could be improved when the die edge pin and routing layer corresponding to die pin are determined in advance of implementing auto routing.
- Moreover, the decision transformer-based (image-based) method could further optimize the auto routing results by refining at least the detours, dense routing areas and redundant trace bendings.