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**Object Detection in Automated Software Testing**

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Abstract

Een abstract bevat een volledige samenvatting van de application note (AN). Door het abstract te lezen kunnen lezers bepalen of de AN interessant voor hen. Dat betekent dat je een abstract zo objectief en aantrekkelijk mogelijk schrijft zodat er zoveel mogelijk lezers je AN lezen. In de praktijk komt dit neer op een prikkelende insteek.

Een abstract bestaat uit strikt de volgende onderdelen in de volgorde waarin ze voorkomen:

- In één tot twee zinnen de AN kunnen samenvatten. Dit is het moeilijkste stuk. Hoe vat je de volledige AN van introductie tot conclusie samen in één tot twee zinnen die aanzetten tot lezen van het abstract/AN?

- Licht het probleem wat deze AN wil oplossen toe. Je kan het ook zien als het doel van het project. Start met de maatschappelijke context toe te lichten. Vermeld vervolgens dat probleem.

- Vertel hoe je dit probleem oplost. Hoe wordt het probleem aangepakt en waar is deze aanpak op gebaseerd?

- Vervolgens worden de resultaten toegelicht of wordt het belangrijkste resultaat vermeld. Zorg zeker dat je hier het resultaat vermeldt dat rechtstreeks een oplossing geeft voor het vermelde probleem. Je kan mogelijks een kort discussiepunt aanhalen. Dit discussiepunt kan ook bij de conclusie aangeraakt worden.

- Geef een korte conclusie van het werk dat in de AN uit de doeken wordt gedaan. Je kan dit zelfs vanuit een ander standpunt concluderen. Heb je bereikt wat je wou bereiken?

- Sluit af met een zeer beknopte zin waar je de mogelijke meerwaarde van het werk naar de toekomst toe tot de kern vat.

**Voorbeeld:**

De eerste stap naar goede AN van junior-collega’s is het opstellen van een template die het voorbeeld geeft en ook toelicht hoe een AN geschreven moet worden. Junior-collega’s moeten meerdere malen in de opleiding verslagen opstellen. Deze AN zal dienen als template voor de verslagen. Wanneer een template verplicht wordt door een opleidingsonderdeel (OLOD) bevat deze vaak geen concrete uitleg wat een sectie in houdt. Bovendien bevat de template vaak geen voorbeelden. Als gevolg kiezen junior-collega’s vaak hun eigen weg met de template waardoor er veel verschillende versies ontstaan. Het nut van de AN als template is dan verdwenen. Dit abstract en deze AN benadert een strikt gedefinieerde template waardoor deze laatste niet meer voor interpretatie vatbaar is en de AN het volledige nut heeft. Deze template die de AN beschrijft bevat alle verplichte secties. De secties lichten toe welke informatie er geschreven moet worden. Vervolgens wordt een voorbeeld gegeven van een dergelijke sectie. Dit voorbeeld voldoet uiteraard aan alle voorschriften en kan dus gebruikt worden door de lezer om een extra indruk te krijgen van de sectie in kwestie. De informatie in elke template is gedetailleerd voorzien. Ook de voorbeelden zijn goed aan te vullen en is reeds in enkele secties gebeurd, maar vraagt toch nog extra werk. Immers, enkele secties zijn eenvoudiger te voorzien van voorbeelden dan andere omwille van de scope van de sectie. De efficiëntie van de template zal in de loop van de tijd moeten blijken via feedback van de gebruikers van de AN-template. De originele opzet van de AN-template is bereikt en de informatie is volledig, maar de template kan nog aangesterkt worden met voorbeelden. De ontwikkeling van deze AN die over de gehele opleiding gebruikt wordt, zal de kwaliteit van de AN van alle junior-collega’s doen toenemen.

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1. Introduction

Wat is de aanleiding van het onderzoek? Wat is de probleemstelling?

Wat is de achtergrond van je probleemstelling om het te kunnen kaderen in het geheel?

Wat is je onderzoeksvraag (denk aan SMART)? Zijn er deelvragen? Zo ja, welke?

Baken je onderwerp duidelijk af. Wat bespreek je wel en niet, waarom niet?

Wat is de praktische relevantie van je onderzoek?

Wat is je vertrekpunt? Zijn er belangrijke (wetenschappelijke) artikelen van waaruit je start?

Wat is je doelstelling? Wat tracht je te bereiken?

Spreekt niet over je opdracht als een “ik moest dit doen voor …”, maar gebruik objectieve en informatieve zinnen in de tegenwoordige tijd. Spreek nooit in persoon (ik of wij), maar zorg dat het logisch klinkt dat dit onderzoek gedaan is en leg de focus op wat er onderzocht/uitgewerkt wordt.

Tot slot, voeg je een leeswijzer toe waarin je bespreekt wat je per hoofdstuk afhandelt.

In recent years, extensive research has resulted in great leaps in the field of machine learning. Many different machine learning models are available to be used in a wide variety of applications by anyone. One such application that has not received as much attention as other applications is automated software testing. A reason for this might be that machine learning is a great solution to automate solving problems that previously could only be solved efficiently by humans (e.g. detecting cats in images). Meanwhile, many solutions exist for automated software testing. For example, Selenium is a library available in many languages that facilitates automated testing in the browser. The library allows for interaction with web pages by retrieving the desired elements. In most cases this works fine. However, being able to retrieve an element using the library is not an assurance that it is visible to the user. Thus, the goal of the project is to discover whether machine learning is a viable solution to this problem. More specifically, object detection is the subcategory of machine learning that applies in this case. The research question can then be formulated as: ‘How can object detection be used in the automated software testing process?’.

In more practical terms, the goal of the project is to develop a proof-of-concept of the use of object detection in automated testing. This includes deciding which object detection model(s) to use and developing a user interface to facilitate the training and testing of the object detection models on different web pages, as well as an API that can be used to perform object detection inference in an automated testing environment. Developing an object detection model is not in the scope since there are many pre-trained models available that can be applied to the project. The input of the model consists of screenshots of the elements that are to be detected. The model should be able to detect the elements at different positions on the screen and different scales, most other variations should not be detected since this should make the test fail (e.g. element in wrong colour should not be detected).

A few papers on the topic of user interface element detection have been published [1, 2, 3, 4, 5, 6]. However, all except one share a common problem that prevents their solutions from being applied to this project. Namely, they attempt to detect as many UI elements as possible and classifying them in certain categories (e.g. text, image, button, slider…). However, the aforementioned use case requires the detection of specific elements to confirm whether they are being displayed and subsequently perform actions on them. For instance, it is not the desired result to classify all buttons on a web page as buttons, but rather to detect all instances of a specific button. *Yeh et al.* [6] did propose a solution for detecting UI elements by providing screenshots of the specific elements. Their solution looks promising but unfortunately the paper was published in 2009, making the technology used in the paper very outdated. Nonetheless their paper can provide some useful insights.

First, section 2 discusses the materials and methods that were employed in the project. More specifically, the programming language and frameworks (2.1), object detection models (2.2), and data augmentation (2.3). Next, section 3 presents the results that were achieved. Section 4 then proceeds to examine and discuss these results. Finally, section 5 formulates a conclusion and reflection.

1. Material and methods

Welke materialen (i.e. hardware en software) kan je gebruiken en heb je met elkaar vergeleken?

Welke materialen waren niet nuttig en waarom niet? Bespreek de keuzes en afwegingen. Gebruik hier overzichtelijke tabellen met de nuttige evaluatiecriteria. Elk criterium moet verdedigbaar zijn waarom het vermeld staat in de tabel en waarom het vergeleken moest worden.

Hoe komt het geheel van materialen samen of welke methode wordt gebruikt om alles te integreren?

Zorg voor schematische voorstellingen (i.e. flowdiagram) van je methode en leg dat schema uit.

Neem enkel nuttige afbeeldingen op. Denk aan lijsten en flowdiagrammen en architectuurschema’s. Refereer naar elke afbeelding vanuit de tekst. De referentie moet je eerst tegenkomen in de tekst, pas daarna toon je de afbeelding. Met andere woorden een logo of een foto van hardware waar je niets expliciet op toont (met een nummer of pijl), is niet professioneel.

Gebruik steeds referenties voor elk stuk hardware of informatie die je hierin zet. Hier staat geen eigen resultaat in, dus alles is ergens van gehaald. Waar je die informatie van haalt, komma is belangrijk voor je wetenschappelijk onderzoek. Dat is je beginpunt voor de vergelijkende studie die ook in dit hoofdstuk staat, waarmee je onderbouwt welke keuze er qua hardware en software is gemaakt.

Geef geen uitleg over de componenten en de technieken die standaard gekend zijn of waarvan de uitleg duidelijk elders te lezen valt. Je gebruikt hier steeds referenties voor en enkel als het in een les is gezien, hoef je hier geen referentie bij te geven. Je mag van de lezer verwachten dat ze een elektronica-ICT-basis hebben. Bij twijfel, komma voeg je toch best een referentie toe.

* 1. Programming language and deep learning frameworks
  2. Object detection models
     1. Comparison

To perform object detection, pretrained models are used and fine-tuned on a dataset containing the webpage elements. A large variety of pretrained models is available, so to avoid spending a great deal of time testing all of them, a selection is made based on the most important qualifiers. These were deemed to be accuracy, speed, and availability.

Firstly, accuracy determines how good a model is at performing object detection on a specific dataset. This dataset is the popular Common Objects in Context (COCO) dataset [7]. Every model that was researched performed a benchmark on the COCO dataset. Most used the COCO validation set, a few used the test-dev set, and some others didn’t specify. The accuracies between these different COCO sets are generally very similar. The accuracy on COCO is expressed as the average precision (AP) with an Intersection over Union (IoU) threshold ranging from 0.5 to 0.95 with steps of 0.05 [8]. This threshold determines when a bounding box is accepted as correct. The IoU is calculated as follows [9]:

This means that if the bounding box coming out of the model and the true bounding box align perfectly, the IoU will be 1. The AP is usually represented as a percentage and is sometimes also called mean average precision (mAP).

Secondly, speed refers to how much time a model spends to detect objects in an image. This is very dependent on the quality of hardware that is used. Consequently, it is difficult to compare the speed of different models without performing benchmarking for all of them. However, the amount of Floating Point Operations (FLOPs[[1]](#footnote-1)) that the model has to perform on an image can function as an estimate of efficiency and complexity [10]. Therefore, it can also function as an estimate of how much time a model needs to process an image. Some models unfortunately did not mention the number of FLOPs so the Frames Per Second (FPS) was used as the alternative.

Lastly, the availability of a model determines how easy it is to get the model up and running. The availability was split into three categories from low to high availability: download, library, and library without the need for data loading. A model that is only available through download is the hardest to get up and running since the entire setup must be figured out and performed by the developer. A model that is available directly through a library or framework is easier to use because their documentation tends to be relatively thorough. However, the data must still be loaded in and modified appropriately by the developer. Some libraries don’t require this and simply use a configuration file, these models are easiest to use and set up.

There is large collection of object detection models available. Comparing every one of them however would be a waste of time. A considerable portion of models are already outdated and easily surpassed by newer state-of-the-art models. The determine which models to compare, three different avenues where explored. First, a brief literature study of object detection model reviews was conducted to ascertain the most popular models. From this literature study can be concluded that YOLO, Faster R-CNN, and SSD are three of the most popular models [11, 12, 13, 14, 15]. Another avenue trough which to find popular models is to check which models are available directly from machine learning frameworks such as PyTorch [16], TensorFlow [17] and Ultralytics [18]. These models are Faster-CNN, SSD, FCOS, RetinaNet, YOLO, RT-DETR, and more. Lastly, another way to find models is to look at the COCO leaderboard [19]. Most of the models that appear in a published paper and have benchmarked on the COCO test-dev set appear on this leaderboard. Currently, Co-DETR is the best performing model in terms of accuracy. Some other state-of-the-art models were found on the leaderboard and compared.

Taking inspiration from the work of *Ouchra and Belangour* [20], a Weighted Scoring Model (WSM) was used to determine which models should be the focus of the project. Table 1 contains all the models that were compared together with their accuracy score, speed score, availability score and total weighted score. The scores were derived from their respective specifications. As mentioned, the accuracy was determined using the reported accuracy of the model on the COCO dataset. The accuracy score was then calculated as a value between 0 and 100, where the model with the lowest accuracy has a score of 0, and the highest a score of 100, the rest in between. The speed score was calculated in the same way, lowest amount of FLOPs gets a score of 100, highest a score of 0. If the FLOPs were not reported, the FPS was used as a fallback. As mentioned above, the availability was split into three categories. The lowest availability category receives a score of 0, the middle category 50, and the highest availability category gets a score of 100. Attachment 7.1 contains the complete table with all the accuracy, FLOPs and FPS metrics, as well as the sources of the data. Finally, a weight between 0 and 1 was assigned to the accuracy speed and availability. This weight represents the expected importance of each metric in the context of the project. Since speed is not imperative, it was assigned a weight of 0.3, while accuracy was assigned a weight of 0.6. The availability receives a very small weight of 0.1 since it is the least important factor that determines the quality of the model. These weights are by no means set in stone, but changing the weights slightly results in the same models receiving the highest score. The weighted total score is then once again a score between 0 and 100. The top 3 models are highlighted in the table below: YOLOv9-E, RT-DETR-X, and Co-DINO. The accuracy of YOLOv9-E and RT-DETR-X is around 10% lower than Co-DINO, which is significant. However, the combination of superior speed and availability places these models right behind Co-DINO. Even if the weights are changed slightly (while still reflecting their importance in the project), the YOLOv9, RT-DETR and Co-DINO models always end up in the top 5. In the case of YOLOv9 and RT-DETR a variant other than the highlighted one could be used since the scores are very similar and the slight increase in accuracy might not be worth the decreased speed. Usually, variants of a model perform similarly. However, Co-DETR is a special case since it is more of a technique that can be applied to existing DETR models. Therefore, the two Co-DETR variants in the table perform very differently due to Co-DINO and Co-Deformable-DETR being completely different DETR models. From this weighted scoring model comparison can be concluded that YOLOv9, RT-DETR, and Co-DINO should be the focus of the project.

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| --- | --- | --- | --- | --- | --- |
| **Model name** | **Model variant** | **Accuracy score** | **Speed score** | **Availability score** | **Weighted total score** |
| YOLOX | s | 42.30 | 98.98 | 0.00 | 55.07 |
| m | 57.95 | 96.33 | 0.00 | 63.67 |
| l | 64.79 | 91.72 | 0.00 | 66.39 |
| x | 68.22 | 84.59 | 0.00 | 66.31 |
| YOLOv7 |  | 68.46 | 94.59 | 0.00 | 69.45 |
| X | 72.62 | 89.78 | 0.00 | 70.50 |
| W6 | 76.77 | 80.19 | 0.00 | 70.12 |
| E6 | 79.95 | 71.44 | 0.00 | 69.40 |
| D6 | 80.93 | 54.99 | 0.00 | 65.06 |
| E6E | 82.15 | 52.94 | 0.00 | 65.17 |
| YOLOv8 | n | 34.47 | 100.00 | 100.00 | 60.68 |
| s | 53.06 | 98.88 | 100.00 | 71.50 |
| m | 66.01 | 96.06 | 100.00 | 78.43 |
| l | 72.62 | 91.17 | 100.00 | 80.92 |
| x | 75.06 | 85.95 | 100.00 | 80.82 |
| YOLOv9 | S | 57.70 | 98.98 | 100.00 | 74.32 |
| M | 68.95 | 96.16 | 100.00 | 80.22 |
| C | 72.86 | 94.69 | 100.00 | 82.12 |
| **E** | **79.22** | **89.64** | **100.00** | **84.42** |
| RT-DETR | L | 72.86 | 94.29 | 100.00 | 82.00 |
| **X** | **77.26** | **87.29** | **100.00** | **82.55** |
| Co-DETR | **Co-DINO** | **100.00** | **84.76** | **0.00** | **85.43** |
| Co-Deformable-DETR | 86.31 | 51.99 | 0.00 | 67.38 |
| Faster R-CNN | R50-FPN | 33.74 | 75.28 | 50.00 | 47.83 |
| R50-FPN | 41.56 | 13.17 | 50.00 | 33.89 |
| R101-FPN | 45.97 | 8.85 | 50.00 | 35.23 |
| X101-FPN | 48.41 | 2.79 | 50.00 | 34.88 |
| R-FCN |  | 20.29 | 0.00 | 0.00 | 12.18 |
| SSD | 300 VGG16 | 0.00 | 34.24 | 50.00 | 15.27 |
| FCOS | R50-FPN | 40.59 | 89.80 | 50.00 | 56.29 |
| RetinaNet | R50-FPN | 32.27 | 70.77 | 50.00 | 45.60 |
| R50 | 37.90 | 11.93 | 50.00 | 31.32 |
| R101 | 42.05 | 11.93 | 50.00 | 33.81 |
| InternImage | T | 63.33 | 85.26 | 0.00 | 63.57 |
| S | 64.79 | 81.32 | 0.00 | 63.27 |
| B | 66.26 | 72.24 | 0.00 | 61.43 |
| L | 80.44 | 21.60 | 0.00 | 54.74 |
| XL | 80.68 | 0.00 | 0.00 | 48.41 |
| **Weight** |  | **0.60** | **0.30** | **0.10** |  |

Table 1: Weighted Score Model comparison of popular and/or state-of-the-art object detection models

* 1. Data augmentation

Data augmentation is the practice of expanding a dataset by performing certain transformations on the elements of the dataset. This allows the model to learn invariant features and prevents overfitting [21]. It also increases the size of the dataset, which is important in this project since the dataset only consists of a few screenshots of the website. There are numerous augmentations that can be performed such as resizing, rotating, translating, changing colour, flipping, noise, etc [22]. However, a lot of the augmentations are not desired in this project. For example, changing the colour of the images in the dataset is not desired since the model should only detect the elements in the correct colour. The same goes for flipping, rotating, and shearing. There are a few data augmentations that can be applied in the context of this project. Firstly, the images can be resized to allow the model to detect the elements at different sizes. This is desired since changing the size of the browser window could change the dimensions of the elements within. It is important to resize only the part of the image within the bounding box. Resizing the entire image would be pointless since the image must be resized again before being input into the model. Secondly, the part of the image withing the bounding box can be translated to a different position inside the image to prevent the model from overfitting to a specific position. Lastly, even though the model shouldn’t be invariant to colour, noise can still be added to prevent overfitting and to allow the model to still detect the element when there are other elements in the vicinity. These are the most important data augmentations that can be applied. It should be noted that these augmentations should be applied to each other as well. For example, the original images are randomly resized. Then all the images, including the resized ones, are randomly translated. Finally, noise is added to all the images. Depending on the number of times an augmentation is applied, this can exponentially increase the size of the dataset.

1. Results

Meerdere projecten of deelonderwerpen worden als andere alinea’s uitgeschreven, mogelijks met elk hun eigen ondertitel. Zorg voor een duidelijke structuur die dan ook in hoofdstuk 4 voorkomt wanneer je elk deel bespreekt. Mocht het geheel geïntegreerd zijn tot één compleet project, mag dat als een apart project met eigen ondertitel gezien worden.

Schrijf resultaten per onderzoeksmethode of deelonderwerp per alinea. Indien nodig voor de structuur, kan je de informatie bundelen per onderdeel met elk hun eigen ondertitel. Dit zijn dan eventueel derde niveau ondertitels indien er meerdere projecten zijn. Zie hieronder voor een voorbeeld.

Beperk het schrijven tot effectief uitgevoerd werk en zonder opinie, want deze komt onder hoofdstuk 4.

Dit deel kan print screens, foto’s en schema’s bevatten. Zorg wel steeds dat ze goed leesbaar zijn. Zorg voor nette foto’s waarbij er geen andere ‘rommel’ zichtbaar is op de foto. Zorg voor verzorgd beeldmateriaal, want alles wat op je beeldmateriaal staat, moet uit te leggen zijn. Net als in hoofdstuk 2 refereer je eerst naar de foto, alvorens je ze laat zien. Bespreek objectief wat er op elke illustratie te zien is.

* 1. Project 1
     1. Design A
     2. Design B
  2. Project 2
     1. Option X
     2. Option Y
  3. Total project

1. Discussion

Reflecteer en bespreek in dezelfde structuur als hierboven elk (deel)resultaat. Koppel het resultaat terug naar de onderzoeksvraag of een deelvraag of probleemstelling. Geef een verklaring aan de resultaten en durf iets te concluderen. Wat kan je uit de objectieve resultaten afleiden of concluderen ?

Zorg voor validiteit van het onderzoek. Waarom was het nuttig? Wat was de meerwaarde? Wat weet je nu meer? Wat mis je nog van informatie en kan je aanraden als vervolg?

Koppel elk eindresultaat aan de verwachtingen en maak suggesties voor verder onderzoek (i.e. Future work). Wat had je verwacht? Bewijst dit nu iets? Of waarom is het volgens jou niet gelopen zoals verwacht? Wat kan er nu verder onderzocht worden?

1. Conclusion

Schrijf eventuele aanbevelingen die je kan concluderen uit je werk, of rapporteer kort een advies en/of besluit. Wat kan je uit heel de opdracht met zekerheid besluiten? Wat voor advies kan je geven op basis van je onderzoek? Is je onderzoeksvraag concreet beantwoord, of wat is de reden dat dit nu niet mogelijk is?

Reflecteer over de hele opdracht, probleemstelling en resultaten. Geef je mening, maar geef dit dan ook duidelijk aan dat dit mening is. Schrijf nog steeds niet in een ik-boodschap, maar wees wel concreet (e.g. “Het aansturen van de AI met behulp van de CM-3 kern lijkt op eerste zicht te voldoen aan de vooropgestelde structuur en betrouwbaarheid van de antwoorden. Echter is er nog geen zekerheid of de validiteit gehaald is en lijkt dit ook niet mogelijk in huidige opstelling.”). Welke nieuwe inzichten zijn er bijgekomen?

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1. Attachment

Alle eigen bronnen die niet via een referentie te voorzien waren, maar die wel relevant zijn of informatie die te groot is om als kleine afbeelding toe te voegen in de AN.

Geprint kan een bijlage zich beperken tot een opsomming die digitaal te raadplegen is.

* 1. Comparison of object detection models

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Model** | | **Accuracy** | | |
| **Name** | **Variant** | **Score** | **mAP (%)** | **Dataset** |
| YOLOX | s | 42.30 | 40.50 | COCO |
| m | 57.95 | 46.90 | COCO |
| l | 64.79 | 49.70 | COCO |
| x | 68.22 | 51.10 | COCO |
| YOLOv7 |  | 68.46 | 51.20 | COCO val |
| X | 72.62 | 52.90 | COCO val |
| W6 | 76.77 | 54.60 | COCO val |
| E6 | 79.95 | 55.90 | COCO val |
| D6 | 80.93 | 56.30 | COCO val |
| E6E | 82.15 | 56.80 | COCO val |
| YOLOv8 | n | 34.47 | 37.30 | COCO val |
| s | 53.06 | 44.90 | COCO val |
| m | 66.01 | 50.20 | COCO val |
| l | 72.62 | 52.90 | COCO val |
| x | 75.06 | 53.90 | COCO val |
| YOLOv9 | S | 57.70 | 46.80 | COCO val |
| M | 68.95 | 51.40 | COCO val |
| C | 72.86 | 53.00 | COCO val |
| **E** | **79.22** | **55.60** | **COCO val** |
| RT-DETR | L | 72.86 | 53.00 | COCO val |
| **X** | **77.26** | **54.80** | **COCO val** |
| Co-DETR | **Co-DINO** | **100.00** | **64.10** | **COCO val** |
| Co-Deformable-DETR | 86.31 | 58.50 | COCO val |
| Faster R-CNN | R50-FPN | 33.74 | 37.00 | COCO val |
| R50-FPN | 41.56 | 40.20 | COCO val |
| R101-FPN | 45.97 | 42.00 | COCO val |
| X101-FPN | 48.41 | 43.00 | COCO val |
| R-FCN |  | 20.29 | 31.50 | COCO val |
| SSD | 300 VGG16 | 0.00 | 23.20 | COCO test-dev |
| FCOS | R50-FPN | 40.59 | 39.80 | COCO test-dev |
| RetinaNet | R50-FPN | 32.27 | 36.40 | COCO minival |
| R50 | 37.90 | 38.70 | COCO val |
| R101 | 42.05 | 40.40 | COCO val |
| InternImage | T | 63.33 | 49.10 | COCO |
| S | 64.79 | 49.70 | COCO |
| B | 66.26 | 50.30 | COCO |
| L | 80.44 | 56.10 | COCO |
| XL | 80.68 | 56.20 | COCO |
| **Weight** |  | **0.60** |  |  |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Model** | | **Speed** | | |
| **Name** | **Variant** | **Score** | **FLOPs (B)** | **FPS** |
| YOLOX | s | 98.98 | 26.80 | 102.04 |
| m | 96.33 | 73.80 | 81.30 |
| l | 91.72 | 155.60 | 68.97 |
| x | 84.59 | 281.90 | 57.80 |
| YOLOv7 |  | 94.59 | 104.70 | 161.00 |
| X | 89.78 | 189.90 | 114.00 |
| W6 | 80.19 | 360.00 | 84.00 |
| E6 | 71.44 | 515.20 | 56.00 |
| D6 | 54.99 | 806.80 | 44.00 |
| E6E | 52.94 | 843.20 | 36.00 |
| YOLOv8 | n | 100.00 | 8.70 |  |
| s | 98.88 | 28.60 |  |
| m | 96.06 | 78.60 |  |
| l | 91.17 | 165.20 |  |
| x | 85.95 | 257.80 |  |
| YOLOv9 | S | 98.98 | 26.70 |  |
| M | 96.16 | 76.80 |  |
| C | 94.69 | 102.80 |  |
| **E** | **89.64** | **192.50** |  |
| RT-DETR | L | 94.29 | 110.00 |  |
| **X** | **87.29** | **234.00** |  |
| Co-DETR | **Co-DINO** | **84.76** | **279.00** |  |
| Co-Deformable-DETR | 51.99 | 860.00 |  |
| Faster R-CNN | R50-FPN | 75.28 | 447.00 | 10.20 |
| R50-FPN | 13.17 |  | 26.32 |
| R101-FPN | 8.85 |  | 19.61 |
| X101-FPN | 2.79 |  | 10.20 |
| R-FCN |  | 0.00 |  | 5.88 |
| SSD | 300 VGG16 | 34.24 |  | 59.00 |
| FCOS | R50-FPN | 89.80 | 189.60 |  |
| RetinaNet | R50-FPN | 70.77 | 527.00 | 24.39 |
| R50 | 11.93 |  | 24.39 |
| R101 | 11.93 |  | 24.39 |
| InternImage | T | 85.26 | 270.00 |  |
| S | 81.32 | 340.00 |  |
| B | 72.24 | 501.00 |  |
| L | 21.60 | 1399.00 |  |
| XL | 0.00 | 1782.00 |  |
| **Weight** |  | **0.30** |  |  |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Model** | | **Availability** | | |
| **Name** | **Variant** | **Score** | **How** | **Where** |
| YOLOX | s | 0.00 | download | [23] |
| m | 0.00 | download |
| l | 0.00 | download |
| x | 0.00 | download |
| YOLOv7 |  | 0.00 | download | [24] |
| X | 0.00 | download |
| W6 | 0.00 | download |
| E6 | 0.00 | download |
| D6 | 0.00 | download |
| E6E | 0.00 | download |
| YOLOv8 | n | 100.00 | lib, no data loading | [25] |
| s | 100.00 | lib, no data loading |
| m | 100.00 | lib, no data loading |
| l | 100.00 | lib, no data loading |
| x | 100.00 | lib, no data loading |
| YOLOv9 | S | 100.00 | lib, no data loading | [26] |
| M | 100.00 | lib, no data loading |
| C | 100.00 | lib, no data loading |
| **E** | **100.00** | **lib, no data loading** |
| RT-DETR | L | 100.00 | lib, no data loading | [27] |
| **X** | **100.00** | **lib, no data loading** |
| Co-DETR | **Co-DINO** | **0.00** | **download** | [28] |
| Co-Deformable-DETR | 0.00 | download |
| Faster R-CNN | R50-FPN | 50.00 | lib | [29] |
| R50-FPN | 50.00 | lib | [30] |
| R101-FPN | 50.00 | lib |
| X101-FPN | 50.00 | lib |
| R-FCN |  | 0.00 | download | [31] |
| SSD | 300 VGG16 | 50.00 | lib | [32] |
| FCOS | R50-FPN | 50.00 | lib | [33] |
| RetinaNet | R50-FPN | 50.00 | lib | [34] |
| R50 | 50.00 | lib | [30] |
| R101 | 50.00 | lib |
| InternImage | T | 0.00 | download | [35] |
| S | 0.00 | download |
| B | 0.00 | download |
| L | 0.00 | download |
| XL | 0.00 | download |
| **Weight** |  | **0.10** |  |  |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Model** | | **Scoring** | | **Data source** |
| **Name** | **Variant** | **Weighted score** | **Rank** |  |
| YOLOX | s | 55.07 | 27 | [23] |
| m | 63.67 | 21 |
| l | 66.39 | 17 |
| x | 66.31 | 18 |
| YOLOv7 |  | 69.45 | 14 | [24] |
| X | 70.50 | 12 |
| W6 | 70.12 | 13 |
| E6 | 69.40 | 15 |
| D6 | 65.06 | 20 |
| E6E | 65.17 | 19 |
| YOLOv8 | n | 60.68 | 25 | [25] |
| s | 71.50 | 11 |
| m | 78.43 | 9 |
| l | 80.92 | 6 |
| x | 80.82 | 7 |
| YOLOv9 | S | 74.32 | 10 | [26] |
| M | 80.22 | 8 |
| C | 82.12 | 4 |
| **E** | **84.42** | **2** |
| RT-DETR | L | 82.00 | 5 | [27] |
| **X** | **82.55** | **3** |
| Co-DETR | **Co-DINO** | **85.43** | **1** | [28] |
| Co-Deformable-DETR | 67.38 | 16 |
| Faster R-CNN | R50-FPN | 47.83 | 30 | [36] |
| R50-FPN | 33.89 | 34 | [30] |
| R101-FPN | 35.23 | 32 |
| X101-FPN | 34.88 | 33 |
| R-FCN |  | 12.18 | 38 | [31] |
| SSD | 300 VGG16 | 15.27 | 37 | [37] |
| FCOS | R50-FPN | 56.29 | 26 | [38] |
| RetinaNet | R50-FPN | 45.60 | 31 | [36] |
| R50 | 31.32 | 36 | [30] |
| R101 | 33.81 | 35 |
| InternImage | T | 63.57 | 22 | [35] |
| S | 63.27 | 23 |
| B | 61.43 | 24 |
| L | 54.74 | 28 |
| XL | 48.41 | 29 |
| **Weight** |  |  |  |  |

1. Don’t confuse FLOPs (Floating Point Operations) with FLOPS (Floating Point Operations per Second) [10]. [↑](#footnote-ref-1)