Enhanced Coinduction

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Curriculum vitae

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Samenvatting

Coinductie, de duale van inductie, is een fundamenteel principe voor het definiëren van oneindige objecten, en het bewijzen van eigenschappen van zulke objecten. Het belangrijkste voorbeeld van coinductie in de informatica is *bisimulatie*, een algemene karakterisatie van equivalentie tussen systemen met oneindig of circulair gedrag, met een concrete bewijsmethode. Coinductieve technieken verschaffen nuttige bewijsprincipes voor verschillende onderzoeksgebieden zoals de theorie van concurrency, de studie van oneindige datastructuren en de automatentheorie.

De brede toepasbaarheid en toenemende interesse in coinductieve technieken zijn gebaseerd op de theorie van *coalgebra's*. Dit is een wiskunde theorie waarin we eigenschappen van toestandsgebaseerde modellen van berekening kunnen begrijpen en bewijzen op een hoog abstractieniveau, en deze eigenschappen vervolgens toepassen op concrete systemen. De theorie van coalgebra's geeft een structureel en algemeen perspectief op bisimulatie en coinductie, met een canonieke karakterisatie van equivalentie en bijbehorende bewijsprincipes.

In dit proefschrift ontwikkelen we technieken die coinductief redeneren vereenvoudigen en verbeteren. We gebruiken hiervoor de theorie van coalgebra's, om algemeen toepasbare methoden te verkrijgen. In het eerste deel van het proefschrift introduceren we verbeteringen van coinductieve bewijsprincipes, en in het tweede gedeelte van coinductieve definitieprincipes.

We introduceren een coalgebraische theorie van verbeterde bewijstechnieken voor bisimilariteit, in Hoofdstuk 4. Onze theorie generaliseert de zogeheten *up-to-technieken*, die geintroduceerd zijn door Milner en Sangorgi om het rederen over processen te vereenvoudigen, van processen naar een breed scala aan toestandsgebaseerde systemen, zoals (niet)deterministische automaten, systemen die oneindige rijtjes representeren en transitiesystemen met kwantitatieve informatie. In Hoofdstuk 2 passen we deze technieken toe om te redeneren over formele talen. In Hoofdstuk 5 worden onze bewijsprincipes verder gegeneraliseerd, op basis van een algemeen perspectief op coinductieve predicaten, zoals geïntroduceerd door Hermida en Jacobs. Met deze generalisatie verkrijgen we verbeterde bewijsprincipes voor willekeurige coinductieve predicaten, wat we toepassen om nieuwe methoden te verkijgen voor het redeneren over simulatie van transitiesystemen, taalinclusie van automaten met kwantitatieve informatie, en divergentie van processen.

Coinductieve definitietechnieken zijn geschikt voor het definiëren en bestuderen van de semantiek van talen. Turi en Plotkin hebben getoond dat men een compositionele semantiek kan verkrijgen door de interactie tussen syntax (gemodelleerd door algebra's) en observaties (gemodelleerd door coalgebra's) te specificeren door middel van een zogeheten distributieve wet. In Hoofdstuk 6 laten we zien hoe zulke distributieve wetten geïntegreerd kunnen worden met recursieve vergelijkingen, om zo het specificeren van talen te vereenvoudigen. Het belangrijkste resultaat uit dit hoofdstuk is dat de interpretatie van een specificatie, die recursieve gelijkheden van een bepaalde vorm kan bevatten, compositioneel is, en dat de bewijsprincipes uit eerdere hoofdstukken gebruikt kunnen worden.

Distributieve wetten kunnen nuttig zijn om coinductief gedefinieerde talen te bestuderen, maar ze zijn soms moeilijk te beschrijven. In Hoofdstuk 7 laten we zien hoe distributieve wetten gepresenteerd kunnen worden als quotient van andere distributieve wetten, die op hun beurt makkelijk te presenteren zijn met gebruik van bestaande technieken. We passen onze techniek toe om eenvoudig distributieve wetten af te leiden voor de semantiek van operaties op oneinidige rijtjes en contextvrije grammatica's.

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